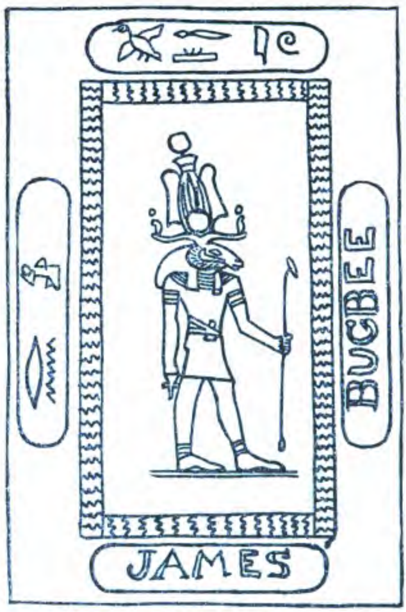
BUGBEE
JAMES

ELECTRICAL

ENGINEERING LEAFLETS

BY

PROFESSOR E. J. HOUSTON, PH. D.
AND
PROFESSOR A. E. KENNELLY, F.R.A.S.

INTERMEDIATE GRADE

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PREFACE.

THE Electrical Engineering Leaflets have been prepared for the purpose of presenting, concisely but accurately, some of the fundamental principles of electrical science, as employed in engineering practice. They have been arranged under three grades; namely, the Elementary, the Intermediate, and the Advanced.

The Elementary Grade is intended for those electrical artisans, linemen, motormen, central station workmen, or electrical mechanics generally, who may not have advanced sufficiently far in their studies to warrant their undertaking the other grades. Here the mathematical treatment is limited to arithmetic, and the principles are illustrated by examples taken from actual practice.

The Intermediate Grade is intended for students of electricity in high schools and colleges. In this grade a certain knowledge of the subjects of electricity and physics generally is assumed, and a fuller mathematical treatment is adopted. These leaflets, moreover, contain such information concerning the science of electricity, as should be acquired by those desiring general mental culture.

The Advanced Grade is designed for students taking special courses in electrical engineering in colleges or universities. Here the treatment is more condensed and mathematical than in the other grades.

Although the three grades have been especially pre-

pared for the particular classes of students referred to, yet it is believed that they will all prove of value to the general reading public, as offering a ready means for acquiring that knowledge, which the present extended use and rapidly increasing commercial employment of electricity necessitates.

Laboratory of Houston & Kennelly,

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INTERMEDIATE GRADE.

No. 1.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

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INTERMEDIATE GRADE.

ELECTRICAL EFFECTS.

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1. The friction of a glass rod against silk causes both the glass and the silk to acquire a property they did not previously possess, of attracting light bodies; *i. e.*, shreds of paper or cotton, in their vicinity. This is an electrical effect. In addition to this, when the glass is vigorously rubbed, crackling sounds are heard, and, in a dark room, faint gleams of bluish light accompany the sound. Moreover, if the rod while vigorously excited, be held near the face, a peculiar sensation is felt, like that caused by the passage of cobwebs over the face.

Both glass and silk after being rubbed together, are said to have acquired an *electric charge.*

2. The exact nature of the process whereby the rubbing together of two substances produces an electric charge is not known, nor is the exact nature of the charge itself understood.

It is known, however, that the presence of an electrical charge on any body or bodies is always accompanied by a strained condition in the surrounding space; but whether this strained condition is the cause of the electrical charge or charges, or whether it is their effect is as yet unknown.

All space is believed to be filled with an extremely tenuous, elastic medium, called the *ether*. The ether not only pervades all free space, but even exists in the interspaces between the ultimate particles of all solid bodies, so that it may be said in this sense to permeate all matter. Light and radiant heat are particular forms of wave-motion-disturbance in the ether; and it is generally believed that the force of gravitation is transmitted through this medium.

3. Although the exact manner in which the rubbing together of two bodies produces the strained condition in the neighboring ether is not known, yet it is undoubtedly due to the contact of dissimilar substances. When any two dissimilar substances are brought into contact, even without friction, an electrical charge is produced at their contact surfaces, varying in amount with the nature of the substances, as well as with the character of their surfaces; *i. e.*, with the degree of surface dissimilarity, so to speak.

4. The charge which accompanies the contact of two dissimilar substances cannot be augmented by continuing the friction between them if both substances are conductors, but it may be very greatly augmented by continued successive surface contact or friction, if one or both substances are non-conductors.

5. In a lightning flash, which Franklin proved by his classic experiment with the kite in 1752; to be a very powerful electric spark, the crackling sounds observed in the experiment with the glass rod, are augmented to the intensity of thunder. Lightning discharges, as is well known, may fuse metal work, and rend or tear masonry.

6. The discharge of a charged body by any means, as by a spark, produces momentarily what is called an electric current; and, indeed, the establishment of a charge is also attended by a current. In nearly all such cases the current is of but momentary character. A number of successive, momentary discharges following one another with sufficient rapidity produces an approximate steady electric current.

7. The dynamo electric machine is a ready source of powerful electric currents. The passage of powerful currents through conductors is attended by heating effects. After a dynamo has been generating current for some time, its coils of wire become sensibly warmed. When passed through a metallic conductor an electric current may even melt or fuse the conductor if the area or cross-section in the latter is too small.

8. In the incandescent lamp the passage of an electric current through a carbon thread or filament, raises it to a high degree of incandescence. The filament is enclosed by a glass chamber, from which all the oxygen has been exhausted, and care is taken to prevent the current strength from becoming sufficiently strong to fuse or volatilize the filament.

When a powerful electric current is sent through two

carbon rods which are first in contact, and are then gradually separated by about one-eighth of an inch, a powerful luminous discharge called the voltaic arc passes between the carbon points.

9. The passage of an electric current through a conductor not only produces heat in the conductor, but also invariably produces magnetic effects which are readily observed under certain circumstances. For instance, the passage of a powerful electric current through the wire coils on the frame of a dynamo machine, produces powerful magnetic effects, and a bar of iron brought near to these magnets will be powerfully magnetized and attracted.

10. The electric current also possesses the property of decomposing chemical solutions through which it passes; for example, if an electric current be led, under suitable conditions, through a solution of copper sulphate it will decompose the salt in the solution, and deposit metallic copper in a coherent and adherent layer upon any conducting surface suitably connected with the leading-in wires. This decomposition is called *electrolysis.*

11. Electric currents, therefore, produce a variety of effects which may be grouped as follows :—

Electrical Effects.

- (*1*) Luminous, as in sparks or in electric lamp.
- (*2*) Thermal, or heating, as in fusion of wire.
- (*3*) Mechanical, as in the disruptive effects of lightning discharge.
- (*4*) Physiological, as in shock to human body.
- (*5*) Magnetic, as in dynamo magnet.
- (*6*) Electrolytic, as in electroplating.

12. It is well known that in order to start a body in motion or to change the direction or velocity of its motion, force must be applied. Thus a train of cars at rest requires the action of the steam engine to set it in motion, and when in motion, the action of the brakes to bring it to a standstill.

A baseball requires a certain force to project it with a certain initial velocity and can only be stopped by the application of opposing forces.

13. Whenever force acts through a distance, it is said to do work, and, in the cases just considered, the motion of the body under the force is an evidence of the performance of work. The word energy is employed in the sense of capability of doing work, or as a store of work, and when work is done, energy is expended, and some store of work has been drawn upon.

The performance of any work whatever, therefore, necessitates the expenditure of energy.

14. When a railroad train is set in motion, steam has to do work by moving the pistons to-and-fro in the cylinders, thus exerting force through a distance. The steam derived its energy from the burning of the coal under the boiler, and the coal in its turn originally derived its energy from the sun, through the absorption of the sun's radiant energy by the vegetable matter from which the coal was formed.

When a baseball is set in motion, the energy of the moving ball—its power of overcoming obstacles—is obtained from the muscular power of the thrower who thus exerted muscular force through a distance. This muscular energy was originally derived from the food

assimilated by his body. In its turn, the food derived its energy from the sun's radiant heat.

When a dynamo is generating an electric current, its driving belt is exerting force upon the rim of the pulley, thus moving it through distance and therefore doing work. It is upon this store of work that the electric current has to draw for the accomplishment of any of its above mentioned characteristic effects.

Fig. 1 shows the electrical transmission of power as contrasted with Fig. 2 which shows the mechanical trans-

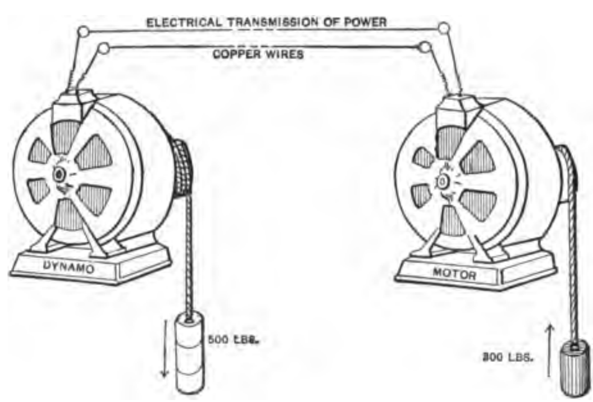

FIG. 1.

mission of power by means of a rope. In each case the falling weight drives the generator, and a motor lifts a smaller weight. The work done by the motor is less than the work expended on the generator by an amount equal to the loss in transmission.

15. It is a well established principle in science that the total amount of energy in the universe is constant. All natural phenomena are due to a change

of form in the energy manifested when force acts on matter, and throughout all these changes whatever energy disappears in one form reappears in some other form.

16. In every transformation some energy is expended in a direction in which it cannot be utilized; that is, in effects which are not desired; such diverted energy is called *wasted energy*, but is only truly wasted from an utilitarian point of view.

Since energy, like matter, is indestructible, it is evident that the *total work done, or the energy which appears*

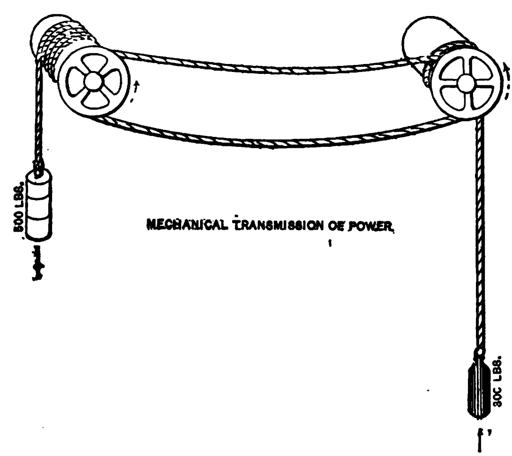

FIG. 2.

in the performance of any machine, must always be exactly equal to the work expended in driving it, the *intake*; but the amount of energy turned to useful account, the *output*, is always less than the intake.

17. The ratio between the output and the intake, that is, the output divided by the intake, is called the *efficiency* of the machine, and is always less than unity;

for example, the efficiency of very large, well constructed dynamos is about 0.95.

18. From what has been said, it will be recognized that the electrical machine forms no exception to the universal rule that to produce any effect a corresponding expenditure of work in some form is necessary.

Syllabus.

An electric charge is accompanied by a strained condition in the ether surrounding the charged body.

The electric charge produced by friction has its origin in the contact of dissimilar molecules.

The passage of an electric current through a conductor is always attended by the production of a *magnetic field.*

When an electric current is passed through a solution of copper sulphate under suitable conditions, a decomposition called electrolysis is effected.

Work is never done or energy expended unless force acts through a distance. Energy is never created; therefore, when work is done some previously existing store of energy is drawn upon. The total store or quantity of energy in the universe is constant.

Every electrical effect is due to energy expended, and the amount of such work can generally be calculated.

The total work done by any machine must always exactly equal in amount the work expended in driving it, but the useful work done by the machine is always less than the work expended in driving it. The ratio of the output of any machine to the intake is called the efficiency and is always less than unity.

No. 2.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

ELECTROMOTIVE FORCE.

19. *Electromotive force* is the name given to the unknown force or cause which produces, or tends to produce, an electric current.

Whenever an electric current flows in a circuit such current is due to an electromotive force (abbreviated E. M. F.) acting on that circuit.

Just as a mechanical force acting on a body produces or tends to produce motion in that body, so an electromotive force acting on a circuit, produces or tends to produce an electric motion; *i. e.*, current in that circuit.

An E. M. force, like all other forces, possesses a definite direction, and as all forces tend to produce motion in their direction, so an E. M. F. tends to produce current in its direction.

20. As in mechanics, two or more forces, when simultaneously acting may, when opposed, neutralize each other and thus produce no motion; or, when acting in the same direction, may aid each other and thus

produce increased motion, so two or more E. M. forces acting simultaneously on the same circuit, when opposed may neutralize each other, and thus produce no current; or when acting in the same direction, may aid each other, and thus produce a stronger current.

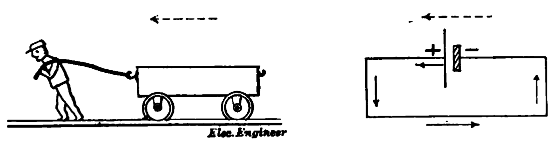

FIG. 3.

Thus in Fig. 3 the man exerting a steady mechanical force moves a car weighing one ton along a level track at a rate of one mile an hour, and the single voltaic cell, symbolized as shown by two lines of unequal length and thickness, produces an E. M. F. which sends a certain current through the conducting circuit.

When, however, as in Fig. 4, the two men apply simultaneously equal mechanical forces to the car in opposite directions, a neutralization or balance is effected and no motion is produced. So the two voltaic cells

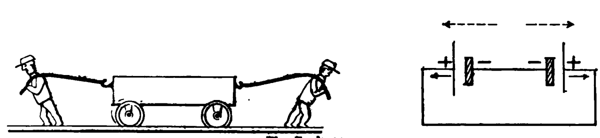

FIG. 4.

connected in opposition in the same circuit neutralize or balance each other and no current is produced.

Again in Fig. 5 the two equal mechanical forces applied simultaneously in the same direction, move a car weighing two tons at the rate of one mile an hour, and

the two voltaic cells connected in series, so that their E. M. F.'s aid each other, produce a double E. M. F. that can send twice the current through the circuit.

An E. M. F. may, therefore, originate a current, may increase the strength of a current already existing, or may oppose and weaken or altogether neutralize such current.

21. E. M. F. is measured in units named *volts*. Large E. M. F.'s are sometimes expressed in kilovolts and small E. M. F.'s in millivolts or microvolts, (*i. e.*, thousanths and millionths of a volt). Thus the E. M. F. produced by a frictional or influence machine which will cause an electric spark discharge over an air space of

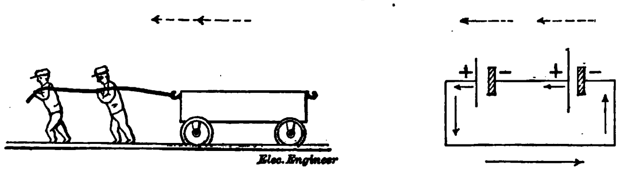

FIG. 5.

one inch between brass knobs might be 75,000 volts, or 75 kilovolts. The E. M. F. of a gravity or bluestone cell such as is frequently used in telegraphy is about 1.08 volts.

The usual standard of E. M. F. for testing and comparative purposes is a special form of voltaic cell called the *Clark cell.* It is composed of pure chemicals and made with great care. It is accepted as having an E. M. F. of 1.434 volt at 15°C.

22. The *joule* is the international unit of work and is equal to 0.738 foot-pounds at the latitude of Washington; or, in other words, one joule of work will

raise a pound of matter at the latitude of Washington through the distance of 0.7381 foot.

The *watt* is the international unit of activity or power, or of the rate of working per second of time, and is an activity of one joule per second. That is to say, a force which will raise one pound at the latitude of Washington through the distance of 0.738 foot in a second, expends work at the rate of one watt, or one joule per second.

The prefixes of *kilo-* and *mega-* are employed for the multiples of 1,000 and 1,000,000 respectively, and are often used as convenient abbreviations. Thus a kilowatt is 1,000 watts, and represents 738 foot-pounds expended per second at Washington. The "*horse-power*" is a unit of activity introduced by James Watt, and is in common engineering use. It represents an activity of 550 foot-pounds per second at Greenwich or 746 watts; so that,

$$1 \text{ H. P.} = 0.746 \text{ kilowatt,}$$
$$\text{or } 1 \text{ K. W.} = 1.34 \text{ H. P.}$$

23. It is necessary to carefully distinguish between work or energy (joules) and activity or power (watts). Work is an expenditure of energy, and is equal to the product of a force and the distance through which that force acts. Activity is the rate of expending energy or doing work, and is found, or at least averaged, by dividing the work done by the time occupied in doing it. The same amount of work is done when a weight of one pound is raised through one foot, whether it be raised in minute or in one second, but the rate at which the work one is done, or energy expended, is sixty times greater in the latter case.

24. E. M. F.'s are produced by devices called *electric sources.* Electric sources are of various kinds and may be conveniently grouped as follows.

Dynamo electric machines. (Producing E. M. F. from 1 to 7000 volts or more.)

Voltaic cells. (Producing singly E. M. F. of 0.5 to 2.5 volts.)

Thermo-electric couples. (Producing an E. M. F. of a few millivolts.)

Frictional electric machines. (Producing an E. M. F. of many kilovolts.)

The terminals of an electric source, *i. e.*, the points from which the current is assumed to leave the source, and again enter it after having passed through the circuit, are termed its *poles* or terminals; the pole from which the current is conventionally assumed to leave the source being called the *positive pole*, and that at which it again enters the source after having passed through the circuit being called the *negative pole.*

It has been pointed out (Par. 14) that unless a mechanical force moves through a distance, it does no work. In the same way, an E. M. F. does no work unless it produces a current. But when an E. M. F. produces a current in a conducting circuit it does work, and the energy necessary to do this work is supplied by the electric source.

25. From an engineering standpoint the most important electric source is the dynamo electric machine.

The first dynamo electric machine, a mere toy in point of dimensions, was invented and constructed by Faraday, in 1831. At the present time dynamos are made up to 3,750 kilowatts capacity.

The voltaic cell is the next electric source in order of practical importance. The output of a cell is, however, very small by comparison with an ordinary dynamo, and rarely exceeds 15 watts. A number of cells connected together so as to form a single source or *battery*, can, of course, increase the output proportionally. Batteries, however, are never used for the production of any considerable amount of electric power.

26. Electromotive forces differ not only in magnitude, but in variability, or time-rate-of-change. Thus arise two general divisions of E. M. F., viz., the *continuous* and the *alternating*. An E. M. F. that has always the same direction is said to be *continuous*. An E. M. F. that alternately and periodically reverses its direction, is said to be *alternating*. As a continuous E. M. F. produces, or tends to produce, a continuous current, so an alternating E. M. F. produces, or tends to produce, an alternating or *oscillating* current.

Continuous E. M. F.'s are further divided into *steady* and *pulsating*. Steady E. M. F.'s are, for brief periods at least, practically produced by voltaic batteries and thermopiles. Continuous current dynamos (so-called), always produce in reality, *fluctuating* or *pulsating* E. M. F.'s although the fluctuations may in some dynamos be so slight and rapid as to escape notice.

Alternating E. M. F.'s are either *symmetrical* or *dissymmetrical*, according as the positive and negative waves, allowing for changes of direction, are or are not similar and equal. Alternating current dynamos (*alternators*) usually produce symmetrical E. M. F.'s, while a Ruhmkorff coil with a vibrating spring, operated by a continuous E. M. F., produces a dissymmetrical alternating E.M.F.

The E. M. F. at breaking contact being much greater than the oppositely directed E. M. F. at making.

27. If as in (Fig. 6.) the water in the vessel A, is in communication with the open vertical tubes a, b, c, d, e, f, g, then when the outlet tube B is closed, the level at which the water stands will be the same in all the tubes. But when the outlet is open, the level will be highest in the tube nearest to the reservoir, and lowest in the tube nearest to the outlet, the level in the intermediate tubes being found along the inclined dotted

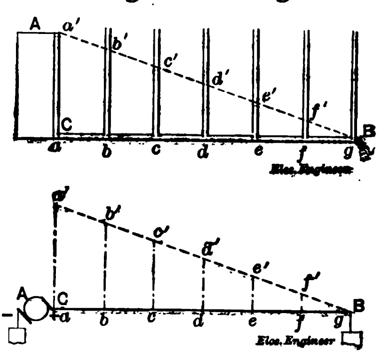

FIG. 6.—Hydraulic and Potential Gradients.

line a', b', c', d', e', f', which line may be called the hydraulic gradient. The force which causes the water to flow through the tube CB, which may be called the water-motive-force, is that due to the difference of level between A and B. Of this force, that fraction which causes the water to flow between any two points of the tube CB as for example between a and b, is that due to the difference of level between a' and b'.

Similarly, the E. M. F. produced by the electric source or dynamo A, which has its positive pole connected to C,

and its negative pole connected to the ground produces a fall of potential or electric pressure along the uniform conducting wire CB, which is connected to the ground at B. The gradient of electric potential being represented by the dotted line a', b', c', d', e', f', and the E. M. F. which drives the current through any portion of the conductor such as a c may be attributed to the *difference of potential* between a' and c', as represented by the difference of length between the lines a a' and c c' measured in volts.

As water flows from a higher to a lower level, so the electric current is assumed to flow from a higher to a lower potential; and as differences of water level constitute what has been called water-motive force, so *difference of electric potential* constitutes electromotive force. The sum of all the *differences of potential* (abbreviated P.D.'s) in a circuit is equal to the total E. M. F. in that circuit.

SYLLABUS.

An E. M. F. has a definite direction and tends to produce an electric current in that direction.

E. M. F. is measured in practical units, called volts, also in micro-, milli-, and kilovolts.

The international unit of work is called the joule.

The international unit of activity; *i. e.*, the joule-per second, is called the watt.

An E. M. F. does no work unless it produces a current.

E. M. F's differ in both magnitude and in variability. They are, therefore, continuous and alternating. Continuous E. M. F's may be steady or pulsating.

No. 3.

Electrical Engineering Leaflets,

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INTERMEDIATE GRADE.

ELECTRIC RESISTANCE.

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28. Resistance is that property of an electric conductor or circuit, in virtue of which an electric current or flow is limited, under any given E. M. F., to a certain value.

The resistance of a water-pipe to the passage of water through it, increases directly with the length of the pipe, and diminishes with the cross sectional area of the pipe. It also varies with the nature of the material from which the pipe is made, and the smoothness of its inner surface. So too, the resistance of a circuit or conductor, varies directly with the length of the conductor, and inversely as its cross-sectional area. It also varies with the nature and physical conditions of the materials of which the conductor is composed.

29. Electric resistances are compared with one another by reference to certain practical electrical units. The unit of resistance is called the *International ohm*, and is the resistance offered by a pure chemical

material of definite dimensions under fixed physical conditions.

The value of the ohm is most conveniently taken as the resistance of a column of pure mercury, one square millimetre in area of cross-section and 106.3 centimetres in length, at the temperature of melting ice. (Zero centigrade or 32° F.) Its value, however, can be defined in terms of any conducting material, such as, approximately, one foot of No. 42 A. W. G. wire of pure copper; and such a wire might be more conveniently maintained as a material standard than a column of liquid mercury; but although mechanically advantageous, such a standard would possess the inconvenience that no two samples of copper wire could be obtained of exactly the same degree of purity and in the same physical condition, while mercury, by redistillation, can be readily obtained chemically pure, and in the same physical condition.

The fundamental unit of electric resistance, in the International C. G. S. system, is that resistance in which the unit of electric current will do work to the extent of one erg (one dyne-centimetre) in one second. This resistance is, however, so extremely small that it would be impracticable to employ it directly, and another unit, the ohm, was selected as the practical unit of electric resistance. The ohm is equal to one billion (1,000,000,000 or 10^9), of the fundamental C. G. S. units of resistance.

30. Conductors are generally made in the form of wires. A circular cross-section is the commonest, though a rectangular section is sometimes employed in dynamo armature-winding for economy of space.

Doubling the length of a wire doubles its resistance. Similarly, halving the length of a wire halves its re-

sistance; doubling the area of cross-section also halves its resistance. Consequently, if a wire of given length be cut into two equal parts, and the two lengths be laid side by side, and so connected with the circuit that the current passes through them in parallel, their *joint resistance*, *i.e.*, the resistance of the two in combination, will be one-fourth of the original resistance of the wire.

We have seen that the resistance of a conductor varies with the nature of the material of which it is composed. As a rule, metals offer a comparatively low resistance to the passage of an electric current, and are, therefore, called electric *conductors*, while hard rubber, glass, gutta-percha, air, etc., offer a comparatively high resistance to the passage of an electric current and are, therefore, called *non-conductors* or *insulators*.

31. For large multiples or submultiples of an ohm, or of any other unit, various prefixes are employed; as for example, the following multiples,

deka...ten times..............	10..	10
hecto...one hundred times.......	100..	10^2
kilo....one thousand times.....	1,000..	10^3
mega...one million times.......	1,000,000..	10^6
bega....one billion times........	1,000,000,000..	10^9
trega ..one trillion times.. ...	1,000,000,000,000..	10^{12}
quega..one quadrillion times....	1,000,000,000,000,000..	10^{15}

and the following submultiples or decimals,

deci....or one tenth........	$1 \div 10$	10^{-1}
centi...or one hundredth..	$1 \div 100$.................	10^{-2}
milli....or one thousandth..	$1 \div 1,000$	10^{-3}
micro...or one millionth....	$1 \div 1,000,000$	10^{-6}
bicro...or one billionth	$1 \div 1,000,000,000$.........	10^{-9}
tricro...or one trillionth....	$1 \div 1\ 000,000,000,000$....	10^{-12}

One c. g. s. unit of resistance is, therefore, a bicrohm.

One millionth of an ohm is a microhm.

One million ohms is a megohm; a billion ohms, a begohm; a trillion ohms is a tregohm; and a quadrillion ohms, a quegohm.

32. For convenience in comparing the resistances of different kinds of material, the standard of comparison is taken as the resistance of unit length and unit area of cross-section; namely, the resistance which would be offered by a cube of the material, one centimetre in length of edge, between opposite faces. The particular resistance of a body referred to unit dimensions in this way is called its *specific resistance* or *resistivity*. For example, iron has, at ordinary temperatures, a resistance about six and a half times that of copper. Thus copper of standard purity (Matthiessen's standard) has a resistivity of 1594 c. g. s. units, at the melting point of ice, or 1.594 microhms, while iron at the same temperature, has a resistivity of 9.687 microhms.

A study of the following table will show that, as a rule, apart from the metals, solids possess the highest resistivities, or are the poorest conductors. Of liquid substances, oils possess the highest resistivity. Water, as measured by Kohlrausch, has a resistivity of 3.75 megohms. As, however, minute traces of impurity enormously diminish this resistivity, it is generally believed that absolutely pure water would be almost a perfect insulator. Water containing 30 per cent. of its weight of nitric acid has a resistivity of 1.29 ohms.

The following is a table of resistivities in International ohms.

Substance.	Temperature.	Resistivity.	Temperature Co-efficient	Authority.
Silver, annealed...	0° C.	1.500 microhms	0.377	Matthiessen.
Silver, hard drawn	"	1.53 "	"	"
Copper, annealed (Matthiessen's standard)......	"	1.594 "	0.388	"
Copper, hard drawn	"	1.629 "	"	"
Iron, annealed....	"	9.687 "	....	"
Nickel, annealed..	"	12.420 "	....	"
Mercury, liquid...	"	94 84 "	0.072	"
German silver.....	"	ab't 20.9 "	0.044	"
Graphite..	"	from 0.0024 to 0.042 ohms	about 0.5	Everett.
Sulphate of zinc, saturated solution............	10°	33.6 ohms....	....	Ewing & Macgregor.
Common salt, solution of minimum resistivity......	10°	4.7 "	....	Kohlrausch & Nippoldt.
Pure water "	"	abont 3.75 megohms	....	Kohlrausch.
Mica.............	20°	84 tregohms..	....	Ayrton & Perry.
Gutta-percha......	24°	449 " ..	....	Latimer Clark.
Hard rubber......	46°	28 quegohms.	....	Ayrton & Perry.
Paraffin	46°	34 "	....	" "
Glass, flint........	0°	16700 "	....	Foussereau.
Porcelain..... .	0°	540 "	....	"

The fourth column gives the *temperature coefficient*, that is the percentage increase in resistivity per degree centigrade increase in temperature. Thus, copper increases 0.388 per cent. per 0° C., *within a range of a few degrees centigrade*, according to Matthiessen's observations, and, taking its resistivity as 1.594 microhms at 0° C. at 5° C., its resistivity would be $1.594 (1 + 5 \times 0.00388) = 1.594 \times 1.0194 = 1.625$ microhms.

From this table of resistivity it is possible to arrive at the resistance of any uniform conductor whose resistivity is given. Thus, if the resistance of a mile of Matthiessen's standard hard-drawn copper wire, having a cross section of one square millimetre is required, for 0° C., we take the resistivity of 1.629 microhms, and since this would be the resistance of a bar one centimetre long and one square centimetre in cross section, the resistance of a centimetre length of wire of 1 square millimetre cross section (100 times less area) would be $100 \times 1.629 = 162.9$ microhms, and the resistance of a mile (160,933 cms.) of this wire would be $162.9 \times 160,933 = 26,215,986$ microhms = 26.2 ohms approximately. The problem of finding the resistance of any wire thus resolves itself into determining its resistivity at the required temperature, its cross sectional area in sq. cms, and its length in cms.

The following table will be useful in these calculations,

1 inch = 2.54 cms. 1 sq. in. = 6.4516 sq. cms.

1 foot = 30.48 cms.

1 mile = (1760 yds) = 160,933 cms.

The temperature coefficient of carbon is negative; namely about — 0.5; that is, a wire or filament of carbon; diminishes about 0.5 per °C. increase, *for a small range of temperature.* At the temperature at which glow lamps are ordinarily operated, their resistance is about half what it is when cold.

The resistivity of insulating substances, diminishes like carbon, with temperature, and this in fact forms a criterion as to the class of substances (conductors or insulators) to which a body belongs.

33. *Conductance* is the inverse of resistance, just as conductivity is the inverse of resistivity.

If, as in Fig. 7, four incandescent lamps be connected to supply mains as shown, and each lamp has when hot a resistance of 100 ohms, (a conductance of $\frac{1}{100}$ or 0.01 mho), the total conductance, since the current is conveyed equally through four different paths, will be the sum of the separate conductances, *i. e.*, 0.04 mho, and the *effective* or *joint resistance* of the combination will be $\frac{1}{0.04} = 25$ ohms.

Just as the total resistance of a number of separate

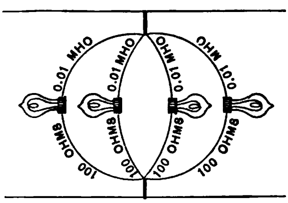


FIG. 7.
RESISTANCES IN PARALLEL.

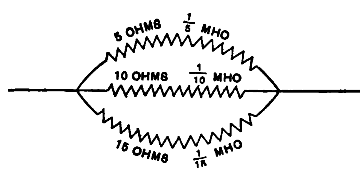


FIG. 8.
RESISTANCES IN PARALLEL.

resistances in series is the sum of those resistances, so the total conductance of a number of separate conductances in parallel, is the sum of those conductances. Thus, if three wires of 5, 10 and 15 ohms respectively, be connected in multiple, as shown in Fig. 8; their respective conductances will be $\frac{1}{5} = 0.2$, $\frac{1}{10} = 0.10$, and $\frac{1}{15} = 0.0667$ mho. The total conductance, therefore, will be 0.3667 mho, and the joint or effective resistance of the three wires, $\frac{1}{0.3667} = 2.727$ ohms.

SYLLABUS.

Resistance is that property of a conductor or circuit which opposes the flow of electricity through it.

The resistance of a conductor varies with its length, cross sectional area, and the nature of its material.

Resistances are compared with each other by reference to a practical standard called the International ohm;

The fundamental C. G. S. unit of resistance is one bicrohm.

The effective resistance of two or more wires in parallel is called their joint resistance.

The resistance of a body referred to unit dimensions is called its specific resistance or resistivity.

No. 4.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ELECTRIC RESISTANCE.

34. The *conductivity* of a material is the inverse of its resistivity, so that the greater the resistivity, the lower the conductivity. Thus the solution of nitric acid in water, which gives the lowest resistivity (1.29 ohms), gives the highest conductivity $\frac{1}{1.29} = 0.77519$, and any other mixture of nitric acid and water would conduct less perfectly, that is, would have a lower conductivity. Conductivity is measured in units called *mhos*, a term derived from the reverse spelling of the word ohm.

35. The resistance of two or more conductors connected in series, that is, joined end to end, is the sum of their separate resistances. Thus three wires which have respectively 5, 10 and 15 ohms resistance, have, when connected in series, a total resistance of 30 ohms. The total resistance in a series circuit is, therefore, the sum of all the resistances in the different parts of that circuit.

36. It is not definitely known whether alloys are mixtures or chemical combinations of their ingredient metals. Electrically, it might be supposed from the resistivity of alloys, that in some cases alloys are mere mixtures, and in others chemical combinations. Thus, alloys of such metals as lead, tin, zinc, and cadmium, behave electrically like bundles of wire made up in the proportions of their respective metals, while alloys of such metals as gold, silver, copper, iron, aluminium, and others, give a resistivity much higher than that which a mere bundle of such wires would lead one to expect.

The temperature coefficient of an alloy is always less than would be expected from the temperature coefficients of its ingredients, and the greater the resistivity of an alloy, the lower will usually be its temperature coefficient. Thus german silver has a resistivity of about 21 microhms (varying considerably with different samples) and a temperature coefficient of about 0.044 per cent. per degree C.; while platinoid has a resistivity of 32.7 microhms, (also varying greatly with different samples), and a temperature coefficient of about 0.021 per cent. per degree C.

37. It has recently been shown that at very low temperatures certain pure metals have exceedingly low resistivities at the lowest temperature at present experimentally attainable (—197° C), and it has been inferred from such observations that at the assumed temperature of absolute zero (—273.6° C.) the resistivity of such metals would be zero, so that a copper wire at such a temperature would have no resistance whatever. It would appear, however, from what has already been

mentioned concerning alloys and their lower temperature coefficients, that their resistivities would still be considable, even at the absolute zero of temperature.

For the same reasons alloys are greatly to be preferred to pure metals for the construction of resistance standards, which should be as nearly constant as possible, in order that variations of temperature may make the least change in the value of their resistances.

38. The materials forming the earth's crust, such as clay, sand, gravel, marl, etc., have, when dry, very high resistivities; but since the ground below a certain depth, is almost invariably moist, even in dry weather, and since the water contains various salts in solution, the resistivity of the entire mass is greatly reduced. When, therefore, a telegraph conductor is carried on poles between two distant points, it is not necessary to have a second or return wire to complete the circuit, since the ground between the two stations may be used as a return conductor, introducing a resistance much less than that which a metallic return conductor would possess. This is due to the enormous area of cross section of the earth, which is so great that the difference in the earth's resistance, as measured between two terminals one mile apart, or one hundred miles apart, is practically imperceptible.

In order to ensure sufficient contact with the ground, the ends of the ground wires are connected with large metallic plates called *ground plates*, usually of copper or iron, and sometimes surrounded by charcoal, buried sufficiently deeply to meet permanently moist strata. In cities, the gas or water pipes, from their extended buried surfaces, serve as excellent telegraph ground plates. The

resistance of the ground in a circuit may vary from a fraction of an ohm to hundreds of ohms, according to the nature of the ground connections, such high resistances being met with in cases where the ground is improperly made, or where the strata in which the plates are buried are permanently dry. Thus arise two varieties of circuits, one, the *metallic circuit*, in which the circuit is metallic throughout; and the other, the *ground return circuit*, in which the ground is used as the return conductor.

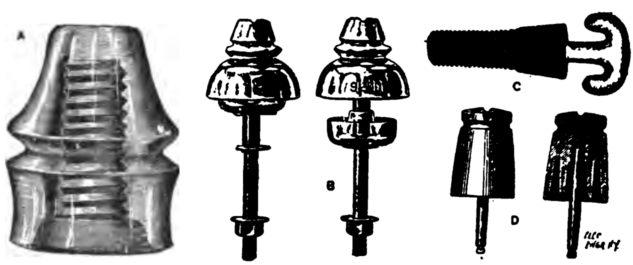


FIG. 9.—VARIETIES OF INSULATORS.

39. On all pole lines the conductor, whether covered or bare, is supported on suitable insulators. Fig. 9 shows a variety of insulators differing in shape and material. A, is a glass insulator; B, an oilcup insulator; C, a hard rubber insulator; and D, a porcelain insulator. These insulators are rigidly supported on pins placed on cross-arms. The resistivity of all these insulating materials is very high and is most conveniently rated in quegohms. The resistance of any ordinary insulator, between the surface of the groove in which the wire is placed and the surface of the supporting pin, would not be less than 500 begohms, but in practice the resistance an insulator offers to the escape of

a current is far less, owing to the conductance of a film of moist dust and dirt on its surface. This is especially true of glass, on account of its hygroscopic nature, and these insulators are, therefore, not well adapted for use in a moist climate. The advantage of an oil insulator arises from the fact that the oil interposes a high resistance path to leakage over the surface, dust and moisture settling to the bottom of the oil, leaving a clean surface.

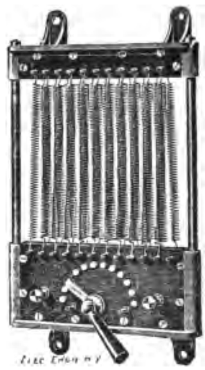
The greater the number of insulators supporting a wire, the greater the number of conducting paths for the escape of current to ground, and hence the greater the leakage. Therefore, the greater the length of conducting circuit, the greater the leakage, and the smaller its insulation resistance. The *apparent insulation* of a line measured in megohms, multiplied by its length in miles, gives its *average apparent insulation per mile in megohm-miles.*

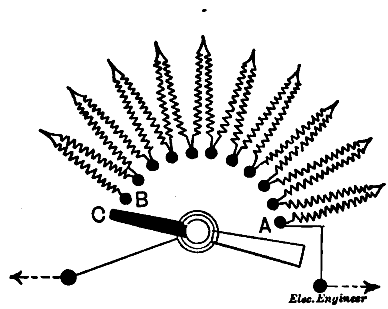
40. Resistances in various forms, usually in coils of wire, are introduced in working circuits for the purpose of controlling or limiting the current strength. In other cases they are introduced for purposes of measurement. In all cases, however, the conditions must be such that the current passing through them shall not produce excessive heating.

For variable resistances, such as are employed for controlling the current strength in working curcuits, iron wires, strips or plates, carbon blocks or discs, or columns of liquid are employed, so arranged that different lengths can be readily introduced or removed from the circuit.

Figs. 10 and 10*a* shows such an arrangement, where, by

the movement of the lever arm, the contact strip c, can be brought into contact with any of the metal buttons from





Figs. 10 and 10*a*.—Resistance Frame and Diagram of Connections.

a to b, thus varying the number of coils of wire in the circuit. The particular instrument shown is designed to

Fig. 11.

carry the current to supply six ordinary incandescent 16 candle-power, 110-volt lamps, without overheating.

Fig. 11 shows a variable resistance or rheostat formed of iron wire, embedded in porcelain enamel, in firm contact with the heavy iron bed-plate. This arrangement

FIG. 12.—WHEATSTONE BRIDGE.

ensures a rapid transference of the heat generated by the current in the wire to the iron plate, and its subsequent diffusion and radiation.

41. Where resistances are employed for the purpose of comparison or measurement, their values in ohms are calibrated with reference to a standard ohm. In this instrument a coil of platinum-silver alloy having the resistance of one ohm at some convenient definite temperature, has its terminals connected to two stout

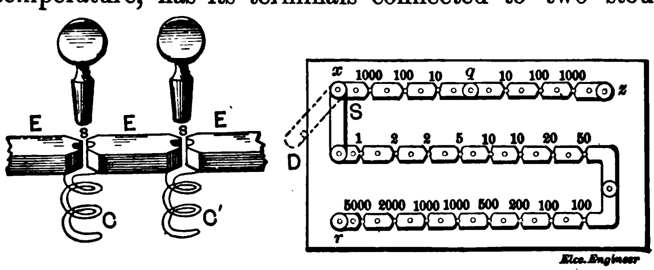


FIG. 13.—DIAGRAM OF CONSTRUCTION OF RESISTANCES IN BRIDGE.

copper rods whose ends dip in mercury cups. The coil and rods within the case are embedded in paraffin wax, a central hollow core being left for the insertion of a

thermometer, when the instrument is submerged in water or oil.

Figs. 12 and 13 represents a common form of resistance box called a *Wheatstone bridge* or *Wheatstone balance*, a plan of which appears beneath together with a diagramatic view of the coils and plugs. By suitable combinations of plugs, the resistance included between the terminals x and r, can be made any integral number of ohms between zero and 10,000.

SYLLABUS.

The conductivity of a material is the reciprocal of its resistivity.

The conductance of a conductor or circuit, is the reciprocal of its resistance, and is measured in mhos.

The total resistance of a number of resistances in series, is the sum of those resistances, and the total conductance of a number of conductances in parallel is the sum of those conductances.

The temperature coefficient of alloys is less than the temperature coefficient of pure metals.

Metallic circuits are metallic throughout. Ground return circuits complete their circuit through the earth's substance.

The resistance of insulators is in practice the resistance of a film of dirt or moisture upon their surfaces. The insulation of a line is expressed in megohm-miles representing the average insulation resistance of a single mile.

Resistances for measurement are usually in coils of wire of a suitable alloy. Resistances for controlling current strength in working circuits are frequently of iron, carbon or water.

No. 5.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ELECTRIC RESISTANCE.

42. The Wheatstone bridge shown in Figs. 12 and 13, (No. 4, Intermediate Grade) is used for determining the resistance of any conducting path or circuit. The electrical connections of the bridge are shown in Fig. 14, where E, is an E. M. F., usually a battery, connected to the terminals q and r. The current from E, divides between the paths $q\ x\ r$ and $q\ z\ r$, where $q\ x$, and $q\ z$, are resistances, usually called the arms of the bridge or balance, $x\ r$, is the adjustable and known resistance under the plugs, while $z\ r$, is the unknown resistance to be measured. Calling the pressure at r, zero, and at q, E, volts, as shown in Fig. 15, the fall of pressure through the resistances will be shown by the inclined lines P $a\ r$, and P $b\ r$. It is evident that if the resistances $q\ x$ and $q\ z$ are equal, and also $x\ r$ and $z\ r$, then by symmetry the pressure $x\ a$, will be equal to the pressure $z\ b$. Consequently, if these points x and z, are connected through a galvanometer, or instrument for detecting a current,

no current will pass, and the galvanometer needle will remain at zero. The resistance in each of the arms $q\ x$ and $q\ z$, are usually 10, 100, or 1000 ohms, and in making a measurement the plugs in the branch $x\ r$, are removed or replaced until the galvanometer shows no current passing. When this is the case the unknown resistance $z\ r$, is equal to the resistance unplugged in $x\ r$, provided that $q\ x$ and $q\ z$, are equal. If $q\ z$, bears any other proportion to $q\ x$, then $z\ r$, bears the same proportion to the unplugged resistance $x\ r$.

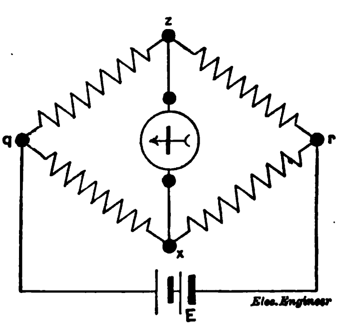


FIG. 14.—DIAGRAM OF WHEATSTONE BRIDGE.

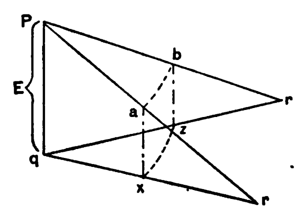


FIG. 15.—DIAGRAM OF FALL OF PRESSURE IN BRANCHES OF WHEATSTONE BRIDGES

43. In order accurately to define, for practical or commercial purposes, the conductivity of copper wire, a standard has been very generally agreed upon based upon the researches of Matthiessen, and called *Matthiessen's standard* of conductivity. The resistivity of soft copper of this standard quality is 1.594 microhms at 0° C., although copper has been obtained at 4 per cent. higher conductivity than that of Matthiessen's standard. A soft copper wire of Matthiessen's standard

conductivity, one metre long and weighing one gramme, will have a resistance of 0.14173 international ohms at 0° C. It is common, however, in specifications, to call for a conductivity in copper of not less than 96 per cent. of Matthiessen's standard. The following is a table of the resistance of ordinary sizes of soft copper wire of Matthiessen's standard conductivity at 20° C. Hard drawn copper has a conductivity of about 2¼ per cent. less than soft annealed copper.

Brown and Sharp Guage No.	Diameter Inch.	Lbs. per Foot.	Lbs. per Mile.	Ohms per Foot.	Ohms per Mile.
0000	0.460	0.6405	3382	0.00004893	0.258
000	0.4096	0.5080	2682	0.00006170	0.326
00	0.3648	0.4028	2127	0.00007780	0.411
0	0.3249	0.3195	1687	0.00009811	0.518
1	0.2893	0.2533	1337	0.0001237	0.653
2	0.2576	0.2009	1061	0.0001560	0.824
3	0.2294	0.1593	841	0.0001967	1.039
4	0.2043	0.1264	667	0.0002489	1.309
5	0.1819	0.1002	529	0.0003128	1.651
6	0.1620	0.07946	420	0.0003944	2.082
7	0 1443	0.06302	333	0.0004973	2.626
8	0.1285	0.04998	264	0.0006271	3.311
9	0.1144	0.03963	209	0.0007908	4.176
10	0.1019	0.03143	166	0.0009972	5.265
11	0.09074	0.02493	132	0.001257	6.636
12	0.08081	0.01977	104	0.001586	8.374

44. When two conducting surfaces are placed lightly in contact, the resistance at the contact is much greater than if the surfaces are pressed firmly together. This is due to the fact that under light pressure, even in the case of the smoothest surfaces, the points of contact are comparatively few, and as the pressure in-

creases, these contact points are increased, thus increasing the available cross-section of contact.

Moreover, films of oxide, the resistivity of which is comparatively high, and which are apt to form rapidly on nearly all metallic surfaces, increase the difficulty of obtaining perfect contact. Consequently, care must be exercised, when introducing apparatus into circuits, that the contact surfaces are free from oxide or grease, and are brought firmly together, especially in cases where the introduction of additional resistance is deleterious.

An excellent form of variable resistance is based upon the preceding principle of resistance offered by light contacts; namely, the carbon rheostat. This rheostat consists essentially of disks or plates of carbon, piled together, and provided with suitable means for varying their pressure. The telephone transmitter in common use employs the principle of variable contact pressure, to impress on the telephone conducting line, variations in the current strength corresponding to the vibrations of sound.

Nearly all the telephone transmitters in common use employ either the principle of variable contact pressure, or the principle of varying the length and cross-section in conducting path through carbon particles, vibrating between relatively non-vibratory electrodes.

45. When the current strength remains constant, the resistance of any part of the circuit depends naturally upon the resistivity of that part, its dimensions and temperature. When, however, the current strength varies rapidly, the form or shape of the conductor also affects its resistance. For instance, a stranded conduc-

tor, that is, a conductor formed of a number of separate wires layed-up together, offers an apparently lower resistance to a rapidly alternating current, that is, to a current rapidly changing its direction, than would a solid conductor of the same length and total cross-section. The cause of this increase of resistance will be considered in a subsequent leaflet.

46. It is now well recognized that lightning discharges partake of a rapidly alternating character. An advantage is therefore secured from the use of a stranded or strip lightning rod, as opposed to a solid rod of the same weight per unit of length.

47. The following is a table of the resistances of various apparatus employed in the commercial applications of electricity.

GALVANOMETERS.

Thomson Mirror Galvanometer	1 ohm to 350,000 ohms.
" " Common resistance	5,000 "
Thomson Marine Galvanometer	5,000 to 50,000 "
D'Arsonval Galvanometers	1 ohm to 750 "
" Common resistance	250 "

AMMETERS.

Resistance usually inversely as maximum current strength measured.

Weston, 15 amperes	0.0022 ohms.

Kelvin Balances, Centiampere balance	160 ohms.
" " Deciampere balance	2 "
" " Ampere balance	0.18 ohm.
" " Composite balance as wattmeter or centiampere balance	30 ohms.
" " as voltmeter (for voltages up to 200 volts)	200 to 500 "

VOLTMETERS.

Cardew voltmeters for 100 volts, about	500 ohms.
Weston voltmeters for 150 volts, about	19,000 "
Thomson Marine voltmeter for 120 volts	1,000 "
Weston alternating current-voltmeters for 120 volts	2,500 to 3,500 "

BATTERIES.

Callaud gravity cell	2 to 4 ohms.
Leclanché	1 ohm.
Bichromate	0.4 "
Edison-Lalande, 300 ampere-hours	0.02 "
Storage cell, 100 ampere-hours	0.005 "

TELEGRAPHY.

Sounders	0.5 to 20
Neutral relays	80 to 300, usually 150
Polar relays	100 to 500, usually about 400

FIRE TELEGRAPHY.

Gongs, about	20 ohms.
Signal box magnets, about	8 "

SUBMARINE TELEGRAPHY.

Speaking mirror	1,000 to 5,000 ohms.
Usually	2,500 "
Siphon recorder coils, about	500 "

TELEPHONY.

Bell telephone, about	75 ohms.
Call bell, from	75 to 1,000 "
Magneto-armature	500 "
Induction coil, primary	0.28 "
Induction coil, secondary	12 to 160 "

DYNAMOS AND MOTORS,

For a given power, or output of these machines, the armature resistance varies approximately as the square of the E. M. F., and for any E. M. F., roughly in inverse ratio to the power.

Armature resistance (warm) of	0.5	K. W.	dynamo	or motor	about	4 ohms.
And between brushes	3	"	"	"	0.4	"
" "	20	"	"	"	0.025	"
" "	100	"	"	"	0.0055	"
" "	200	"	"	"	0.0024	"

ALTERNATING CURRENT TRANSFORMERS.

Resistances of primary and secondary coil vary with frequency of alternation and a variety of other circumstances. Roughly, they vary inversely as the power rating of the machine. The following are a few examples.

0.5	K. W.	primary	21.8 ohm,	Secondary	0.04	ohm.
2	"	"	5.5 ohms	"	0.015	"
20	"	"	0.48 ohm	"	0.0015	"

INCANDESCENT LAMPS.

The resistance varies approximately inversely as candle-power when operated at uniform E. M. F.

Thus at	115	volts	an........ 8	candle-power	lamp,	hot,	500	ohms.
"	"	"	10	"	"	"	"	406	"
"	"	"	16	"	"	"	"	254	"
"	"	"	32	"	"	"	"	127	"

The human body varies enormously in its resistance with the position of electrodes, their surface area, the dryness or moisture of the skin, the duration of the application, and the current strength. Lowest resistance on record, 214 ohms from surface of head to surface of right calf, and 500 ohms from hand to hand each immersed to wrist in salt water. Average resistance under latter conditions 1000 ohms.

The resistance of the lightning rod on the Washington monument (550 feet high) including ground connections is 2.3 ohms.

SYLLABUS.

In a Wheatstone bridge, the value of an unknown resistance is determined by equalizing the potential at

two definite points in a divided circuit, one branch containing an adjustable resistance, and the other the unknown resistance.

Matthiessen's standard of conductivity is based upon measurements made by Matthiessen of the resistivity of the purest copper he was able to obtain.

Hard drawn copper has a conductivity of about 2¼ per cent. less than annealed copper.

The resistance of contacts between surfaces depends upon the nature of the surfaces, their area, and the pressure with which they are brought together.

Since the resistivity of films of metallic oxides is high, the presence of such films should be carefully avoided in jointing conductors.

All carbon rheostats and some telephone transmitters utilize the principle of variable contact pressure.

A stranded conductor offers an apparently lower resistance to a rapidly alternating current than would a solid conductor of the same length and weight. Consequently lightning conductors should be preferably stranded, lightning discharges being usually oscillatory.

No. 6.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ELECTRIC CURRENT.

48. It is evident that the effects produced by the passage of electricity in a circuit are dependent on the time during which the flow is maintained. For example, the amount of work done by an electric motor depends entirely upon the current which is passing through the motor, and also upon the time during which the current is supplied. Again, the amount of heat and light emitted by an electric lamp depends, for a given current, upon the time during which the lamp is lighted. The amount of metal deposited in a plating bath depends similarly, for a given current, upon the time during which the current is supplied.

Any of these electric effects, therefore, must be attributed to the passage of a definite quantity of electrical flow, maintained for a definite time.

49. Just as the flow of water through a pipe may be correctly rated as a certain number of cubic inches per second, so the flow of electricity through a conductor or

circuit may be correctly rated as a certain number of *coulombs* of electricity per second. A coulomb is, therefore, the unit quantity of electricity, and corresponds in cases of electric current to the unit quantity of water in hydraulics, say, a cubic inch.

Since electricity is invisible, a coulomb cannot be seen. It can, however, be rigorously measured by its properties. For example, a coulomb of electricity on passing through a chemical solution, liberates by decomposition perfectly definite quantities of the constituent elements of that solution. For example, a coulomb will deposit 1.118

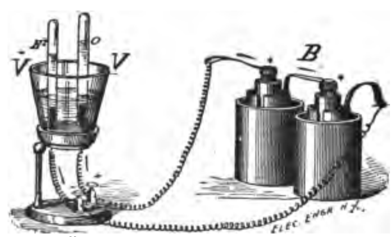


FIG. 16.—ELECTROLYTIC EFFECT OF THE ELECTRIC CURRENT.

milligrammes of silver from a solution of a salt of silver, or will liberate 0.01038 milligramme of hydrogen from water. So rigorously are these relations maintained, that for many years the voltameter shown in Fig. 16, was almost the only instrument for measuring electric current. The current from the battery B, enters the acidulated water in the glass vessel VV, through platinum electrodes at the base connected with the leading-in wires marked + and —. The passage of the electricity causes the water to be decomposed, and causes hydrogen and oxygen to be liberated at the negative and positive electrodes respectively, and the gases evolved collect into the test tube placed over the platinum plates, thus displacing the water

with which the tubes were already filled. Since one milligramme of hydrogen at the standard temperature and pressure (760 cms. of mercury and 0°C.) occupies 11.16 c.c., the reading of the level of liquid in the graduated tubes will show, when corrected for temperature and pressure, the total number of coulombs that have passed through the apparatus.

50. A current of electricity is not a total flow, but a rate of flow, and this distinction must be carefully borne in mind. Thus the voltameter just described does not measure current strength directly. What it measures is the total quantity of electricity which passes in coulombs, and, therefore, it has to be regarded as a *coulomb-meter*.

The unit rate of flow in electricity is called an *ampere*, after a celebrated French electrician, *Ampère*. It has a rate of flow equal to one coulomb of electricity per second; and, just as the rate of flow of water through a pipe may be measured in cubic inches per second, so the flow of electricity through a conducting circuit, or its current strength, may be measured in amperes, or coulombs-per-second.

The *International ampere*, so called because its value is adopted by all civilized nations, is practically defined as that current which when passed through a properly prepared aqueous solution of silver nitrate will liberate 1.118 milligrammes of silver per second. This, as we have already seen, is the amount deposited by a coulomb in any time, and the ampere is to deposit this in one second, since one second is required for the passage of one coulomb under this current strength.

51. When an ampere flows steadily through a circuit during one hour, the total quantity of electricity which passes is 3600 coulombs, this being the number of seconds in an hour. An *ampere-hour* is, therefore a unit of electric quantity equal to 3600 coulombs. This unit is in common use. 112.7 ampere-hours are required for the decomposition of a pound of silver. Similarly 374.3 ampere-hours are required, for the decomposition by electro-plating of a pound of zinc. Again in a voltaic cell one pound of zinc will furnish a quantity of electricity equal to 1,347,500 coulombs or 374.3 ampere-hours, assuming that there is no loss of zinc by local action. If a battery of ten cells in series delivers 374.3 ampere-hours collectively, one pound of zinc will be burnt in each cell.

52. Electric currents may be classed into three different varieties.

(*1.*) The *continuous* current. (*2.*) The *pulsatory* current. (*3.*) The *alternating* current.

The continuous current has constant direction and magnitude, or, if varying, does not vary periodically. Such currents are generally obtained from thermopiles, voltaic or primary cells, and storage or secondary cells.

The pulsatory current is one in which the direction is uniform but the strength varies.

Pulsatory currents are practically used in many forms of signal and telegraphic apparatus, also in some arc light and power circuits. Strictly speaking nearly all continuous current dynamos furnish pulsatory rather than continuous currents, owing to the slight fluctuations produced at the changes of the commutator segments under the brushes. In well designed continuous current dyna-

mos, however, these pulsations are usually so slight, that the current they furnish may be considered as practically continuous. But even in the best designed continuous current dynamo, except in those of the so-called unipolar type, these pulsations do exist.

Alternating currents are those whose direction periodically alternates, and whose current strength is also periodically variable. They are extensively employed in electric lighting and in the transmission of power.

53. The following is a table of current strengths employed in various practical applications:

The aggregate maximum current strength delivered by all the dynamos lighting New York City is about	60 kilo-amperes.
The strength of current employed in electric welding is often	20 to 50 kilo-amperes.
The current strength usually employed in arc lighting is	8 to 10 amperes.
The current strength required to operate the average 110-volt, 16 C. P. lamp is (either alternating or continuous)	0.45 ampere.
The current strength required to operate the average telegraph circuit is	25 to 35 milli-amperes.
The minimum current stated to be appreciable by the Bell telephone	0.6 tricro-ampere.
The minimum current practically appreciable by Thomson mirror galvanometer (one scale division of a semi-millimetre at a distance of one metre), about	20 tricro-amperes.
Alternating current strength hitherto employed in the execution of criminals by electricity (New York State)	3 to 8 amperes.
The average current strength employed in firing electric fuses, about	0.5 ampere.

54. The capability of electricity to produce chemical decomposition is very seldom practically employed for purposes of measuring the current strength in a circuit. It is much more convenient to employ the magnetic effect produced by the current. When an electric

current traverses a conductor, it produces in the space surrounding the conductor what is called a magnetic field, that is, a space permeated by magnetism. When a magnetizable substance is brought into this magnetic field, the passage of the flux through it tends to give it a set or direction, which is more marked when the magnetizable substance possesses a magnetism of its own; *i. e.*, is already magnetized. A magnetizable substance is generally made in the form of a magnetic needle, or it may

FIG. 17.—WESTON AMMETER.

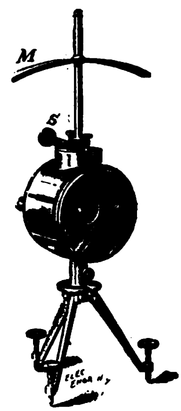


FIG. 18.—THOMSON MIRROR GALVANOMETER, TRIPOD FORM.

be replaced by a movable coil or conductor which possesses a magnetic field when traversed by an electric current. Instruments of this character employed for the measurements of electric currents are called *galvanometers*, *amperemeters*, or *ammeters*. A few galvanometers are shown in the figures.

Fig. 17 shows an ammeter called a Weston ammeter. Here a permanent magnet is employed and a coil of wire

capable of rotation between its poles, is moved by the measured current against the action of a spring. A pointer, suitably fixed to the coil, indicates upon the scale the current strength.

Fig. 18 shows a common form of Thomson mirror galvanometer mounted on a tripod. The current to be measured passes through a circular coil in the instrument, at the centre of which is a small magnetic needle suspended on a silk fiber, and attached to the back of a glass mirror. The *controlling magnet* M, is so supported

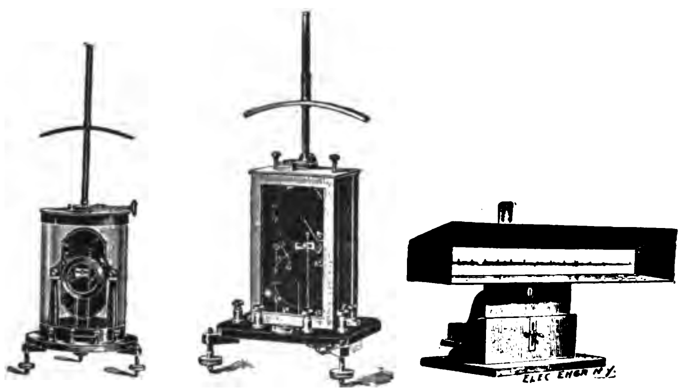


FIG. 19.—THOMSON MIRROR GALVANOMETERS, LAMP AND SCALE.

on a vertical rod that it can be moved up or down the rod, and also rotated by the thumbscrew S. The position of this magnet controls the position of the magnetic needle, and also the sensibility of the instrument. When a current passes through the coil, it causes the magnetic needle, with its mirror to deflect, and a beam of light from a suitably placed lamp is reflected back upon a scale. The movement of the reflected image or spot of light on this scale measures the current strength.

Fig. 19 shows two other forms of Thomson mirror galvanometer, in which two superposed coils of wire are employed with a double magnet system and mirror attached. This arrangement which is called an *astatic system*, secures a high degree of sensibility. A convenient form of scale for use with such instruments, is shown on the right.

SYLLABUS.

The effects produced by an electric current depend upon the time during which the current is passing through the circuit.

The flow of water through a pipe may be conveniently rated in cubic inches per second.

The flow of electricity through a conductor may be conveniently rated in coulombs per second.

The unit quantity of electricity is called a coulomb.

A coulomb of electricity will liberate 1.118 milligrammes of silver from a solution of a salt of silver, or 0.01038 milligramme of hydrogen occupying 0.1116 C.C. at standard temperature and pressure.

The coulombs passing in any circuit may be measured by a voltameter.

The ampere, represents, not the total quantity of electricity which has passed, but the instantaneous rate at which it is passing, that is, its rate of flow.

The international ampere is one coulomb per second.

The magnetic effect is the most convenient effect of a current to employ for measuring its strength, and is used in galvanometers.

No. 7.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

OHM'S LAW.

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55. The current strength in any continuous current circuit depends upon the electromotive force or pressure in the circuit. If the total electromotive force be doubled, then, other things being equal, the current strength will be doubled. In other words, the current strength is proportional to the electromotive force. The current strength in any continuous current circuit also depends upon the resistance of the circuit. If the resistance be doubled, the current strength will be halved; in other words, the current strength is inversely proportional to the resistance.

These effects were discovered by Dr. Ohm, who announced them in a law generally known as Ohm's law; namely: The current strength in a continnous current circuit is obtained by dividing the total electromotive force in the circuit by the total resistance in the circuit.

56. Ohm's law is generally expressed as follows: $C = \frac{E}{R}$, in English speaking countries, where C = current strength in amperes; E = E. M. F. in volts, and R, the resistance in ohms. In foreign countries the equation is usually written

$$I = \frac{E}{R}$$

I, here standing for the *intensity* of the current.

Since, however, at the International Electrical Congress at Chicago in 1893, it was recommended to employ a uniform symbolic notation, in which I was to be used internationally in place of C, this latter symbol being adopted for another purpose, we shall hereafter employ I, to represent current strength.

57. From the formula,

$$I = \frac{E}{R}, \qquad (1.)$$

we obtain,

$$E = I R, \qquad (2.)$$

and

$$R = \frac{E}{I} \qquad (3.)$$

In other words, having given any two of the three essential quantities, electromotive force, resistance and current strength, in a continuous current circuit, the third can always be determined by the foregoing equations. These formulæ are applicable, not only to an entire circuit, but also to any portion of a circuit; thus, the E. M. F. of a conductor which is required to send through it the current it conveys is usually called the "*drop*" in that conductor.

58. For example, in (Fig. 20) where a battery of E.M.F. E, and internal resistance, r_1, is represented in circuit with an electromagnet of resistance r_2 and long wires of total resistance r_3 leading to a circuit closer.

Here $$I = \frac{E}{R} = \frac{E}{r_1 + r_2 + r_3},$$

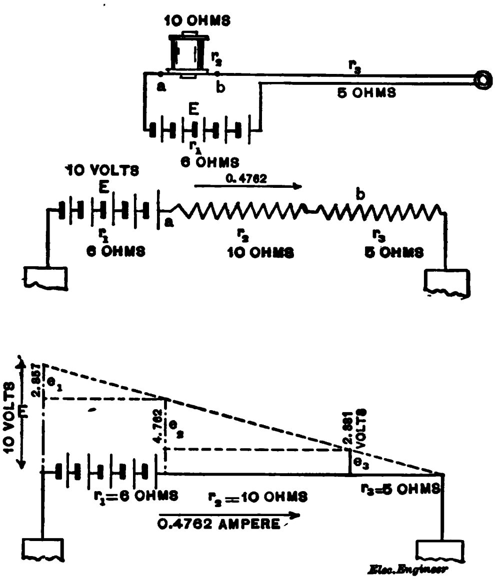

FIG. 20.—DISTRIBUTION OF POTENTIAL DIFFERENCE IN A CIRCUIT.

in which the resistance R is equal to the sum of the separate resistances. Thus if $E = 10$ volts, $r_1 = 6$ ohms, $r_2 = 10$ ohms, $r_3 = 5$ohms, then $R = 21$ ohms, and $I = \frac{10}{21}$ $= 0.4762$ ampere. This current in passing through each resistance r_1, r_2, and r_3 is attended by such a distribution of E. M. F. as will satisfy equation (2). Thus in passing

through r_2, it will be attended by an E. M. F. of $e_2 = 0.4762 \times 10 = 4.762$ volts, and a *voltmeter*, an instrument for measuring electromotive forces, if suitably connected across the terminals of r_2; namely, between a and b, would indicate 4.762 volts. The same relation would be true for r_3, in which there is a *drop* of $0.4762 \times 5 = 2.381$ volts. Again e_1 is the drop in the battery of $0.4762 \times 6 = 2.857$ volts, so that while the current flows, the P. D. at battery terminals $= 10 - 2.857 = 7.143$ volts.

Since $E = e_1 + e_2 + e_3$, it is evident that the total electromotive force in a circuit is equal to the sum of all the separate potential differences, set up in that circuit.

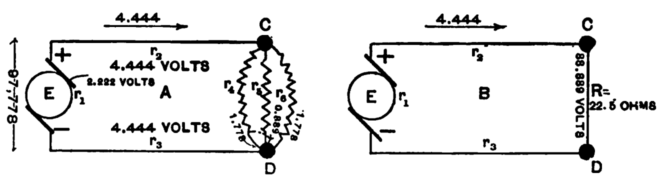

FIG. 21.—APPLICATION OF OHM'S LAW TO A DIVIDED CIRCUIT.

59. The preceding formulæ are also applicable to branch, derived or shunt circuits. Thus, in Fig. 21 A, the dynamo E, whose E. M. F. is 100 volts, and internal resistance r_1, is 0.5 ohm, supplies three branches r_4, r_5, and r_6, of 50, 100, and 50 ohms, respectively, through two leads, each of one ohm.

In this case we may substitute for the three resistances in parallel, their equivalent or joint resistance R, as in Fig. 21 B. By what has been already stated in paragraph 33, the joint conductance of r_4, r_5, and r_6, is $\frac{1}{50} + \frac{1}{100} + \frac{1}{50} = 0.05$, and, therefore, their joint resistance

is $\frac{1}{0.05} = 20$ ohms. The total resistance in the circuit is, therefore, $r_1 + r_2 + r_3 + R = 22.5$ ohms, and the current in the main circuit $\frac{E}{R} = \frac{100}{22.5} = 4.444$ amperes.

The drop in the dynamo armature due to its resistance will, therefore be $E = I\,R = 4.444 \times 0.5 = 2.222$ volts, leaving the P. D. at dynamo terminals 97.778 volts.

The drop in each lead will similarly be 4.444 volts or 8.889 volts in both, leaving 88.889 volts at the terminals C. D.

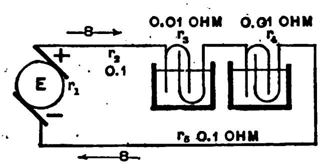

FIG. 22.—APPLICATION OF OHM'S LAW TO A CIRCUIT CONTAINING COUNTER E. M. F.

The current in r_4 will be				$\frac{E}{R} = \frac{88.889}{50} =$ 1.778	amperes.
"	"	" r_5	"	similarly 0.889	"
"	"	" r_6	"	" 1.778	"
				Making the total 4.444	" as before.

60. Fig. 22 represents the case of a low tension dynamo, E, of E.M.F. seven volts, and internal resistance r_1, 0.03 ohms, charging two storage cells in series, of 2.5 volts and 0.01 ohm each, through two leads r_2 and r_5 of 0.1 ohm each. In this case the E. M. F. of the storage cells is opposed to that of the charging battery so that the total E. M. F., $E - e = 7 - 5 = 2$ volts, and the total resistance $r_1 + r_2 + r_3 + r_4 + r_5 = 0.25$ ohm, making the current $I = \frac{E - e}{R} = \frac{2}{0.25} = 8$ amperes.

Here the drop in the dynamo armature due to its resistance will be $E = I\ R = 8 \times 0.03 = 0.24$ volt, leaving a P. D. at dynamo terminals of $7 - 0.24 = 6.76$ volts. The drop in each lead will be $8 \times 0.10 = 0.8$ volts or 1.6 volts, collectively, making the pressure at storage battery terminals 5.16 volts, and the apparent drop in each cell 2.58 volts, of which 2.5 is counter E. M. F., and 0.08 P. D. due to $I\,R$ drop.

61. Ohm's law for the current strength developed by a given impressed E. M. F. in a circuit of given resistance, is not true unless the E. M. F. impressed on the circuit remains constant in strength, or in case it varies, allowance is made for its variation. In the case of alternating current circuits, where the variation in E. M. F. is periodic and obeys a definite law, and where consequently the current strength varies periodically, allowance has to be made for the effect of this variation, and the current strength in such a circuit, is not generally the simple ratio of the E. M. F. to the resistance. The necessary modification of Ohm's law as applied to alternating current circuits, will be explained in a subsequent leaflet.

SYLLABUS.

In any continuous current circuit, the current strength varies directly with the E. M. F. or pressure; *i. e.*, if the pressure be doubled, the current will be doubled, and if the pressure be halved, the current will be halved.

In any continuous current circuit the current strength varies inversely as the resistance; *i. e.*, if the resistance be doubled the current strength will be halved, and *vice-versa*. Both the above relations are expressed in Ohm's law in the equation

$$I = \frac{E}{R}.$$

If E, the total E. M. F. be expressed in volts, and R the total resistance in ohms, then I, the current strength will be expressed in amperes.

The resistance in any circuit can usually be conveniently divided into three parts; namely, the resistance of the source; the resistance of the leads or conductors; and the resistance of the receptive device; and the formula of Ohm's law then becomes

$$I = \frac{E}{r_1 + r_2 + r_3}.$$

The total E. M. F. in a circuit is equal to the sum of the separate E. M. F.'s in the circuit if more than one E. M. F. is acting.

The fall of pressure or "drop" in a conductor carrying a current, is the E. M. F. required to send that current through the conductor.

Ohm's law for current strength is not applicable to other than continuous current circuits, unless allowance is made for variations in E. M. F. In alternating current circuits therefore, where the E. M. F. varies periodically, this law requires modification for the E. M. F.'s that are introduced into the circuit by the variation of the current.

No. 8.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
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A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ELECTRIC CIRCUITS.

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62. The word circuit, literally a circle, is the path which an electric current traverses when it leaves the positive pole of an electric source, or battery of sources, and passes through or influences the various electro-receptive or translating devices placed in its path, re-enters the source or battery at its negative pole, and returns to its starting point at the positive pole, after flowing through the source. In actual practice, the shape of the path is seldom circular. It is evident that all conducting circuits consist essentially of three parts; namely:

(*1.*) Of the source.
(*2.*) Of the conductors.
(*3.*) Of the receptive or translating devices.

The prime object of all electric circuits is to convey an electric current, produced by an electric source, to more or less remote places where the electro-receptive devices are located.

63. The conditions governing the current strength in any circuit will, as already pointed out, be determined in accordance with Ohm's law, by the relations existing between the electromotive forces and the resistances.

The resistance of a circuit will necessarily depend upon the separate resistances of the three parts already referred to, namely, the source, the leads, and the receptive devices, and, since the useful work done by the various receptive devices will depend upon the relation existing between their resistance and the resistance of the rest of the circuit; *i.e.*, that of the leads and sources, it is necessary that the resistance of these separate parts be properly proportioned in order to obtain the desired efficiency.

64. In order to obtain the best relative resistances adapted to the conditions of different cases, a great variety of conducting paths or circuits have been devised. These, however, may readily be grouped under four leading classes; namely:

(*1.*) Series circuits.
(*2.*) Multiple circuits.
(*3.*) Multiple-series circuits.
(*4.*) Series-multiple circuits.

65. In the series circuit of electro-receptive devices all the current passes successively through each electro-receptive device, and returns to the source. For example, in Fig. 23, which represents a Municipal Series Incandescent System, the current leaving the dynamo, E, at its positive or + terminal, passes through the lamps 1, 2, 3, 4, 5, 10, and returns to the dynamo at its negative or

— terminal. Since in such a circuit, the extinguishment of any single lamp would break or open the circuit, and thus render all the other electro-receptive devices inoperative, some form of safety device is always employed automatically to short-circuit any lamp which may become faulty, and thus permit the current to continue to pass through the other devices.

66. A series circuit of electro-receptive or translating devices is generally employed in the case of arc lamps, and of most telegraphic and telephonic apparatus. The resistance of a series circuit is equal to the sum of the separate resistances; consequently, in all such cir-

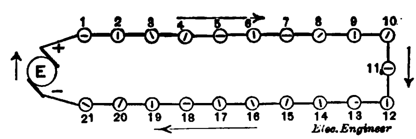

FIG. 23.—"MUNICIPAL" SERIES CIRCUIT OF 21 INCANDESCENT LAMPS.

cuits, as additional translating devices are introduced or removed from the circuit, some arrangement must be provided in the source, which will vary its electromotive force, and so ensure a proper working of the electro-receptive devices by causing the current which passes through them to remain constant.

The series circuit as employed for arc lamps is, for this reason, frequently called a *constant current circuit.* A constant current circuit of variable resistance must necessarily be a circuit of variable E. M. F.

67. Electric sources may also be connected in series; for example, in Fig. 24, which shows two dynamos, E_1 and E_2, connected in series. Here the positive

brush of the dynamo, E_2, is connected with the negative brush of the dynamo, E_1, and their free brushes are connected respectively to the negative and positive leads. In the case of series connection of electric sources, the electromotive force of the single source so provided, is, of course, equal to the sum of the electromotive forces of the separate sources. Dynamos are so coupled when the electro-receptive devices they are intended to operate, require a greater electromotive force than that which either dynamo alone can furnish.

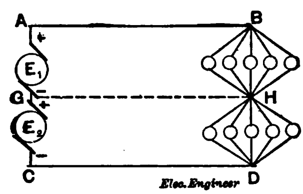

FIG. 24.—SERIES-MULTIPLE ARRANGEMENT OF LAMPS AND SERIES ARRANGEMENT OF DYNAMOS.

68. In the multiple circuit of electro-receptive devices, the separate electro-receptive devices have all their positive terminals connected to a single positive conductor or lead, and all their negative terminals similarly connected to a single negative conductor or lead. The current from the source passes from the positive lead through as many separate branches, or derived circuits, as there are conducting paths offered to it, and, after passing through the receptive devices, returns to the dynamo at the negative lead. Thus, in Fig. 25, the dynamo D, has it positive brush or terminal connected to the positive lead, and its negative brush or terminal connected to the negative lead. The separate receptive devices, in this case a group of lamps, are connected as shown, each

with one of their terminals to the positive lead, and the other to the negative lead. The current leaving the dynamo, branches, as shown by the arrows, and, after passing through the receptive devices, returns to the dynamo.

69. Since in the multiple circuit, the resistance of the entire circuit decreases with every new receptive device added in multiple, it is evident that the current strength in the entire circuit will vary with the number of separate receptive devices; but, since neglecting the drop in the leads, the lamps are all subjected to the same difference of potential, it is evident that this circuit will have between its leads a constant difference

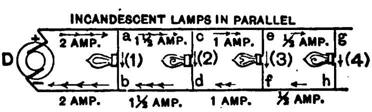

FIG. 25.

of potential, or electrical pressure, depending upon the difference of potential furnished by the dynamo, at its brushes. Such a circuit is, therefore, frequently called *a constant potential circuit.* A constant potential circuit is one in which the current strength in the circuit necessarily varies with the number of devices operated. The electro-receptive devices, however, since their resistances are all equal, will be each traversed by a constant current, because they are acted on by a constant electromotive force.

70. Electric sources may be connected in parallel. Thus, Fig. 26, shows four dynamos of equal electromotive forces, such as would be employed in supply-

ing incandescent lamps connected in multiple. Here all the dynamos have their positive brushes connected to a single *positive lead*, or *bus-bar*, A B, and all their negative terminals similarly connected to a single *negative lead*, or *bus-bar*, C D. The electromotive force of the combination is the same as that of a single dynamo, and the resistance of the combination, much less than that of a single dynamo, as would follow from the rule already stated for determining resistances in parallel.

A *bus-bar*—an abbreviation of *omnibus bar*—receives, as its name indicates, the total current supplied by two or more dynamos.

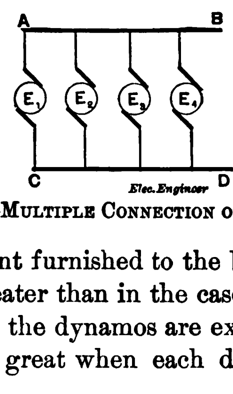

FIG. 26.—MULTIPLE CONNECTION OF DYNAMOS.

The total current furnished to the bus-bars may, therefore, be much greater than in the case of a single dynamo, and, when all the dynamos are exactly equal, will be just four times as great when each dynamo is operated at full load.

71. In the multiple-series circuit, a number of separate electro-receptive devices are connected in separate groups in series, and these groups subsequently connected in parallel.

Fig. 27, shows nine plating baths connected in multiple-series. Here the baths are coupled in separate series groups of three each, and these groups subsequently con-

nected in multiple. This arrangement is, however, almost entirely limited to the case of voltaic cells, and is adopted where it is necessary to obtain such relations between the current strength and the electromotive force as may be required for the best operation of receptive devices connected in the circuit.

72. In the series-multiple circuit, a number of separate electro-receptive devices are connected in separate groups in multiple, and these groups subsequently connected in series. This arrangement is employed in the case of the *three-wire system* for incandescent lamps,

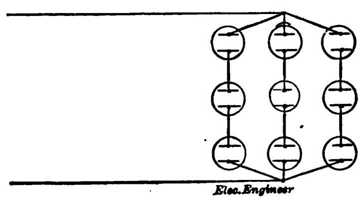

FIG. 27.—ARRANGEMENT OF ELECTROPLATING BATHS IN MULTIPLE-SERIES.

where, as indicated in Fig. 24, the lamps are connected in separate groups in multiple, and these groups subsequently connected in series. In order properly to maintain the electrical pressure at the terminals H B, and H D, of the two groups of lamps when the number of lamps in each group may vary, a third or *neutral wire* G H, is carried from the point H, to the common connection G, of the two dynamos, and the current through this wire automatically tends to equalize the pressure on each side of the system.

Syllabus.

All circuits may be divided into four main classes; viz: series, multiple, multiple-series, and series-multiple.

The resistance of electric devices or sources connected in series is the sum of their separate resistances; the electromotive force of series-connected sources is the sum of their separate electromotive forces.

In the series circuit, the current strength is constant throughout the circuit: a series circuit is, therefore, some. times called a constant current circuit.

In a multiple circuit, the conductance of devices or sources connected in parallel is the sum of their separate conductances.

In the multiple circuit the potential difference, disregarding drop in the leads, is constant. This circuit is, therefore, sometimes called a constant potential circuit.

Voltaic cells are sometimes connected iu multiple-series or in series-multiple.

No. 9.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

THE VOLTAIC CELL.

73. We have already seen that the origin of the E. M. F. produced by the friction of unlike bodies is to be traced to the contact of dissimilar surfaces. Here the energy supplying the electricity is the mechanical energy required to produce the friction. We have also seen that this E. M. F. can be made to produce momentary currents. When the contact of different metallic substances is produced through the agency of a liquid capable of conducting electricity and of being decomposed by it, such contact produces an E. M. F. which can be utilized for the production of a steady current.

74. A device for the ready production of electromotive force by the contact of metallic substances through the intervention of a liquid substance is called a *voltaic cell*. In all cases a voltaic cell consists of two dissimilar substances, generally metals, and an exciting liquid, called the electrolyte. The two metallic substances form, when used in this connection, what is called

a *voltaic couple*, the liquid through whose intervention their contact is continued is called the *electrolyte*, and each of the separate metals of the couple is called an *element*.

Where the amount of current required for use is not excessive, a voltaic cell is one of the most convenient sources of electrical energy. It is named in honor of Alexander Volta, who invented it.

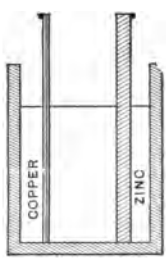

FIG. 28.—SIMPLE FORM OF VOLTAIC CELL ON OPEN CIRCUIT.

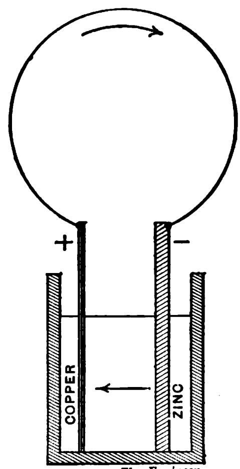

FIG. 29 —SIMPLE FORM OF VOLTAIC CELL ON CLOSED CIRCUIT.

75. When as in Fig. 28, two plates of commercial zinc and copper are plunged in a dilute solution of sulphuric acid in water, the following actions take place; namely,

(*1.*) The acid acts on the zinc which is slowly dissolved with the formation of zinc sulphate, $ZnSO_4$, and the liberation of hydrogen, H_2, according to the following chemical equation,

$$Zn + H_2 SO_4 = ZnSO_4 + H_2.$$

(*2.*) The hydrogen is liberated entirely at the surface of the zinc plate, where the action occurs.

(*3.*) No action occurs at the copper plate.

(*4.*) The chemical action on the zinc plate is attended by the liberation of heat which raises the temperature of the liquid.

When now, the zinc is connected outside of the liquid by means of conducting wire, as shown in Fig. 29, the phenomena change and are as follows:—

(*1.*) The zinc is attacked as before with the formation of zinc sulphate, though not necessarily at the same rate as before.

(*2.*) The hydrogen is now liberated almost entirely at the surface of the copper plate.

(*3.*) The heat liberated during the action now appears in all parts of the circuit and is not confined to the cell. That is to say, the wire becomes warm.

(*4.*) An electric current now traverses the conducting circuit as may be shown by its action on a magnetic needle suspended either near the wire or near the battery.

76. The combination of parts described in connection with the preceding figure constitutes a simple form of voltaic cell. The source of energy which produces the E. M. F. is clearly to be traced to the chemical potential energy, of the plates and electrolyte, liberated during the chemical combination of the positive element with the negative radical of the electrolyte; *i.e.*, the SO_4 ion or radical.

The chemical equation which expresses the activity of the cell is, therefore,

Before action; $Cu + H_2\,SO_4 + Zn.$

After action; $Cu + H_2 + ZnSO_4.$

The action, therefore, evidently removes an atom of zinc for every molecule of $H_2 SO_4$ decomposed, while the hydrogen liberated tends to collect on the surface of the copper plate. Since this hydrogen, by its contact with the copper, tends to produce an E. M. F. directed opposite to that of the cell, its presence tends to decrease the working E. M. F. and various devices are employed to avoid its presence.

Polarization devices in practice provide for either preventing the liberation of the hydrogen or for rapidly absorbing it after formed. Both of these objects are effected by surrounding the plate by some suitable chemical substance. The tendency to the production of a counter-electromotive force by the presence of hydrogen, is called the *polarization* of the cell, and the substance surrounding the negative plate for the purpose of preventing such polarization is called the *depolarizer*.

77. Voltaic cells may be divided into the following general classes; namely,

(*1.*) Cells without depolarizers.

(*2.*) Cells with depolarizers.

Those of the first class are generally called single-fluid cells, and in them, on closed circuit, polarization is apt to prove a very serious defect. The best cells of this class employ for one of the elements a carbon plate. Carbon, as is well known, possesses in a marked degree, the power of dissolving and occluding hydrogen gas.

When an exciting liquid like chromic acid is employed, which, besides acting on the zinc, also possesses the power of combining with and dissolving hydrogen, the polarization, which would otherwise exist, is reduced.

Strictly speaking, then, the fluid in such single-fluid cells, acts both as the exciting and depolarizing fluid.

78. Voltaic cells with depolarizers may be divided into two well defined classes; namely,

(*1.*) Cells with a single fluid and a solid depolarizer, and

(*2.*) Cells with two separate fluids, one exciting, and one depolarizing, with a porous partition between them.

In the simple or voltaic cell shown in Fig. 29, the current produced on the closing of the circuit is conventionally assumed to flow in the direction shown by the arrows; namely, through the electrolyte from the zinc plate to the copper plate, and, outside the electrolyte, from the copper terminal, through the conducting path, to the zinc terminal. Since, according to convention, that pole of the source out from which the electricity flows is the positive pole, and that pole into which it flows, the negative pole, it will be seen that the positive terminal, or electrode, is the terminal connected with the copper plate, while the negative terminal or electrode will be that connected with the zinc plate. Strictly speaking this convention will make the polarity of the plates, where covered by the electrolyte, exactly opposite to the polarity in the parts above the liquid; namely, the zinc plate will be positive in the liquid and the copper plate negative.

It is evident that the above is a mere convention, that the zinc plate cannot be both positive and negative. Indeed, if tested by an electrometer, the zinc plate can be shown to be negative throughout its mass, and the copper plate can be similarly shown to be positive. Still it

is convenient to refer to the copper plate as the negative plate because the current enters it from the liquid, and the zinc plate as the positive plate, because the current issues from it into the liquid; and, moreover, since these terms are sanctioned by general usage we shall employ them in future.

79. It may be interesting, in connection with the preceding, to state the manner in which the convention as to the direction in which the electric current is assumed to flow (namely from the positive to negative) arose. It was originally arbitrarily assumed that the character of the electrification produced by say, catskin against glass, was negative on the catskin and positive on the glass. The glass was, therefore, regarded as having a positive charge, and the catskin, a negative charge, and, when these charges neutralized each other, it was assumed that the charge passed in a momentary current or discharge from the glass to the catskin; *i. e.*, from the positive to the negative substance. When at a later date, Volta's discovery, showed that electric charges were produced by the contact of two dissimilar metals through the intervention of an electrolyte, it was found by the use of electrometers that the charge produced at the copper plate of the battery was of the same sign as that produced on glass by friction. The copper pole was, therefore, taken as the positive pole of the cell, and this being determined, all the other polarities follow.

80. Since hydrogen invariably appears at the surface of the negative plate, a depolarizing substance should be placed so as to surround the negative plate. Where the depolarizer is a liquid, the use of a porous

cell is necessary, in order to prevent the admixture of the exciting with the depolarizing liquid.

The substance employed for the porous cell or partition generally consists of unglazed earthenware. Since the resistivity of the substance of the porous cell is very high, the electric current produced in the cell passes almost entirely through the liquid, following the minute pores or channels in its substance, and the resistance of the cell is necessarily increased. The formation of crystals, or the collection of bubbles of gas in the pores, may also still further increase the resistance. Where the depolarizer is a solid, the use of the porous cell may be dispensed with and its accompanying disadvantages avoided.

Syllabus.

In a voltaic cell, the E. M. F. is produced by the contact of the elements of the voltaic couple with the electrolyte.

The simple chemical solution of zinc in sulphuric acid is attended with a local evolution of heat. The electrochemical solution of zinc in a voltaic cell is attended with a general evolution of heat together with the production of electric current through the circuit. The counter-electromotive force of a cell is generally due to the contact of hydrogen with the negative plate.

Polarization of voltaic cells is avoided either by preventing the liberation of free hydrogen, or its removal by combination, if liberated.

Voltaic cells may be divided into two classes, those with depolarizers, and those without depolarizers.

Voltaic cells with depolarizers are of two classes, namely:

Double fluid cells containing an exciting and a depolarizing fluid; and single fluid cells containing an exciting fluid with a solid depolarizer.

No. 10.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

THE VOLTAIC CELL.

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81. The objections already pointed out concerning the use of single-fluid cells, have prevented, in a great measure, their commercial introduction. We will, therefore, describe but two forms of single fluid batteries.

Fig. 30 shows a form of plunge battery, commonly called a Grenêt, bichromate, or Poggendorf cell, although the first term is most frequently used. This cell consists of a zinc-carbon couple, furnished with two carbon plates and a single zinc plate placed between them. In the form shown, the zinc is supported on a slide rod, so as to enable it to be lifted out of the exciting liquid when the battery is not in use. The exciting liquid consists either of a solution of pure chromic acid, or of a mixture of bichromate of potash and sulphuric acid in water. This mixture forms chromic acid and a salt of soda and is known as electropoion fluid. The Grenêt cell gives an E. M. F. of 1.9 volts; as its resistance is about 0.2 ohm it

would give on closed circuit a current of 9.5 amperes, provided no polarization existed. In practice, however, it would not be advisable to use the cell at so excessive a discharge. It is also important that the zincs should be kept well amalgamated, as otherwise serious local action may occur.

82. Fig. 31 shows another form of single-fluid zinc-carbon battery. The zinc is made in the form of a rod and is surrounded by a group of carbon rods which

FIG. 30.—GRENET CELL.

FIG. 31.—SINGLE-FLUID ZINC-CARBON CELL.

form the negative plate, these rods being connected together by the metal cover, through which the zinc rod passes insulated. The exciting liquid is a solution of sal ammoniac in water. This cell readily polarizes, and, therefore, is only valuable for open circuit work, such as for ringing bells, annunciators, alarms, or other work in

which the cell is given long intervals of rest in which to depolarize.

83. One of the earliest forms of double-fluid cells was invented by Grove. The Grove cell consists of a zinc-platinum couple, immersed in a dilute solution of sulphuric acid and water, and in strong nitric acid, respectively. In the Grove cell, polarization is prevented by the nitric acid surrounding the negative plate, combining with the nascent hydrogen.

84. The high price of platinum rendered Grove's battery very expensive, and Bunsen modified it by replacing the platinum plate with a carbon plate. A form

FIG. 32 —BUNSEN CELL.

of Bunsen cell is shown in Fig. 32. Here the carbon C, is immersed in strong nitric acid contained in a porous jar. A zinc plate, in the form of an open cylinder, surrounds the porous jar, and is immersed in a dilute solution of sulphuric acid in water. The negative terminal is connected with the zinc, and the positive terminal with the carbon plate. Bunsen's cell gives an E. M. F. of 1.96 volts. In the early history of the art, the Grove and

Bunsen cells were almost entirely used for the production of powerful electric currents, but they are now almost entirely superseded by cheaper or better cells.

85. In all the cells thus far described the current strength supplied is subject to considerable variation. Daniell was the first to produce, in 1836, a voltaic cell which furnishes a practically constant current strength on closed circuit, provided the current density in the cell is not too great. The Daniell cell is a zinc-copper couple, immersed, respectively, in dilute aqueous solutions of zinc sulphate and concentrated copper sulphate. In the early form of Daniell cell, the copper sulphate was prevented from mixing with the zinc sulphate by being placed inside a porous jar of unglazed earthenware. Besides the objection to the use of this cell arising from the high resistance already referred to, it was found in practice that the copper, instead of being deposited on the surface of the negative plate, was deposited irregularly on the surface of the porous jar, thus greatly increasing the resistance of the cell. These objections have been obviated by the introduction of the Callaud or Gravity type of Daniell cell.

86. Fig. 33 shows a form of gravity cell as generally constructed. The copper element is placed at the bottom of the glass jar and is provided with an insulated wire that is carried out at the top of the jar. The zinc element, in the form of an open wheel, or crow's foot, is supported near the top of the jar as shown. To charge the cell, enough crystals of copper sulphate are placed in the jar to entirely cover the copper plate, and the jar is filled with water above the upper surface of the zinc

plate. The cell is then placed on short circuit for about twenty-four hours, in order to form enough zinc sul phate in solution to reduce the resistance of the battery.

The constancy of the Daniell or Callaud cell depends on the fact that polarization is almost entirely avoided, and, instead of hydrogen being evolved at the surface of the negative plate, there is deposited a film of pure, highly negative copper. Moreover, the exhaustion of the battery, by the weakening of the battery solution, is also avoided in this cell, since, as fast as the copper sul-

FIG. 33.—GRAVITY DANIELL CELL.

phate is removed from solution fresh material is dissolved from the crystals of copper sulphate surrounding the negative plate, and the solution is thus kept saturated. For each molecule of copper sulphate that is decomposed, one atom of zinc is removed from the zinc plate and a molecule of zinc sulphate formed. There is a tendency, therefore, for the zinc sulphate solution to become concentrated. This is readily avoided by syphoning off a portion of the zinc sulphate solution and replacing it by fresh water. When most of the crystals of copper sulphate

have been dissolved, it is only necessary to throw a few handfuls of fresh crystals into the cell. After the cell has been in use for some time, the two solutions will be observed to be separated from each other by a sharply marked line. The less dense solution of zinc sulphate floats on the denser solution of copper sulphate. A Daniell cell gives an E. M. F. of about 1.072 volts.

87. Fig. 34 shows a form of single-fluid cell, called the Leclanché, with a solid depolarizer that is in very extensive commercial use. This cell consists of a

FIG. 34.—LECLANCHE CELL.

FIG. 35.—EDISON-LALANDE CELL

zinc-carbon element immersed in an exciting solution of sal-ammoniac in water. The carbon plate is placed in a porous jar and is surrounded by crushed carbon and black oxide of manganese, tightly packed in the porous jar. The top of the porous jar is then sealed, a few openings being left for the escape of gas. The carbon plate, with its porous cell, is placed inside a glass jar, as shown, with the zinc element in the form of a cylindrical rod placed beside it. A Leclanché cell gives an E. M. F. of about 1.47 volts. This cell is admirably suited for open-circuited work. It readily polarizes, but if left for

sufficient time on open circuit, recovers its normal condition. It is extensively employed for bell and signalling work.

88. Fig. 35 shows an Edison-Lalande cell of 300 ampere-hours capacity. It consists of a zinc-copper element immersed in a solution of caustic soda in water. The depolarizing substance is a solid; namely, a block of compressed copper oxide, placed in the copper frame of the negative plate. The copper plate is suspended between two parallel plates of zinc, and, being separated from them by only a narrow space, and the plates being comparatively large, the internal resistance of the cell is small, being in the case of the size of cell shown about 0.07 ohm.

The chemical actions which take place are as follows; viz., the caustic soda is decomposed with the formation of a zincate of soda, and the reduction of the cupric oxide at the negative plate to metallic copper. When the cell is exhausted, the zinc plate has to be renewed, and the mass of metallic copper may be converted in a furnace into cupric oxide.

The Edison-Lalande cell has an E. M. F. of about $\frac{2}{3}$ volt. It has practically no local action when left on open circuit, and possesses the advantage of being able to furnish a very powerful current, and also to remain idle for long periods of time.

89. The silver-chloride cell consists of a zinc-silver couple immersed in a dilute solution of sal-ammoniac in water. The silver, usually in the form of a thin wire or strip, is surrounded by a bar or cylinder of fused silver chloride.

When charged, this cell can be hermetically sealed, and in such form can be readily carried about. Owing to the cost of the silver, this cell is only employed where comparatively small currents are required, as in medical use, or for testing purposes. A silver chloride cell has a very nearly uniform E. M. F. of 1.03 volts.

SYLLABUS.

Nearly all practical voltaic cells employ depolarizers either in the shape of liquids or solids. Of cells, employing liquid depolarizers, the Grove, the Bunsen, and the Daniell or Callaud are the most important. Of those employing solid depolarizers, the Leclanché, the Edison-Lalande, and the silver-chloride are the most important.

The Daniell, or Callaud cell is very well adapted to closed circuit work; the Leclanché cell for open circuit work.

The Edison-Lalande cell is suited for intermittent and also for powerful currents.

The silver-chloride cell furnishes a convenient portable form of battery with a fairly constant E. M. F., but gives only a comparatively small current.

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Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

THE VOLTAIC CELL.

90. No matter what form be given to the voltaic cell, it can never reasonably be expected to compete, in point of economy, with a well designed dynamo-electric machine, where any considerable output of electric energy is demanded. The source of energy in the voltaic cell is the chemical potential energy of the plates and of the electrolyte. In the dynamo electric machine the energy liberated from coal, burned under a boiler, is eventually converted into electrical energy by causing the conductors on the armature to cut magnetic flux paths. In the voltaic cell a comparatively expensive metal, zinc, is burned in an exciting liquid, and the output of the cell, is necessarily much higher in price than in the case of the dynamo. Thus, assume the cost of a pound of zinc, sufficiently good to be employed in a battery, to be $0.07. This pound of zinc, as we have seen, would be consumed by a delivery of 1,347,500 coulombs; therefore, if the E. M. F. of the cell is as high as 2 volts, the energy delivered by the

pound of zinc will be 2,695,000 volt-coulombs or joules, and dividing this by the number of seconds in an hour, we obtain 748.6 watt-hours, = 0.7486 K. W. hours. The price of a K. W. hour of electric energy produced from this voltaic cell would, therefore, be $\frac{0.07}{0.7486} = 9.35$ cents in zinc consumed alone, regardless of the cost of the electrolyte, interest, depreciation and attendance.

On the other hand, it is well known that large engines require about 1.8 lbs. of coal to be burned under their boilers for every indicated horse-power-hour delivered to the dynamos, so that with coal costing, say, $3.00 per ton of 2,240 lbs., the cost of a horse-power-hour in coal is 0.241 cent, regardless of water, oil, waste, attendance, interest and depreciation. This represents 0.323 cent per indicated K. W. hour, and with dynamos converting 90 per cent. of the indicated horse power into electrical energy, the cost of coal per K. W. hour is, therefore 0.359 cent. It will, consequently, be seen that the cost of a K. W. hour produced by a voltaic cell, in zinc consumed, is about 26 times the cost of the same amount of energy (3600 joules) produced by a steam dynamo on a large scale.

91. The above has reference only to the case where a voltaic battery is required to produce a large amount of electrical energy. In the case of the steam engine, the necessary expense for attendance, as well as the inconveniences attending the delivery of a very small amount of power, renders the battery a very convenient source of energy for such small powers as driving sewing machines, fans or other similar apparatus.

The amount of power delivered to the moving air by a fan of nine inches in diameter, running at 1,000 revolutions

per minute, is about three watts, increasing very nearly as the cube of the velocity up to a critical speed.

The amount of energy absorbed by an ordinary sewing machine making about 480 stitches per minute, is approximately 12 watts. The efficiency of the small motors required to drive the fan or sewing machine being usually no more than 0.5, about twice the mechanical energy must be supplied electrically in every case.

92. A ready measure of the amount of power which a cell can furnish, neglecting the consequences of polarization, is the square of its E. M. F., divided by its resistance. This may be called the *electrical capability* of the cell and is equal to the number of watts which would be expended by the cell if placed on short circuit, being expressed thus:

$$P = \frac{e^2}{r}.$$

It is evident, therefore, from the above expression that the electrical capability of a cell increases as the square of its E. M. F., and is inversely as its resistance. In the case of any given cell the E. M. F. is beyond control. In any battery the E. M. F. can be increased by adding cells in series. The internal resistance of a cell can be decreased by decreasing the distance between the plates or by increasing their area. The latter is usually the most practical method. It will, therefore, be seen that all methods for increasing the electrical capability of a voltaic source are practically limited to coupling a number of cells together so as to increase the E. M. F. or to decrease the resistance, or both.

The electrical capability of a battery of N cells is N times the electrical capability of a single cell, and is inde-

pendent of the grouping of the cells, provided that the cells are all similar, and are symmetrically grouped. For example, if a cell has an E. M. F. of 2 volts, and an internal resistance of 0.25 ohm, its electrical capability will be $\frac{2 \times 2}{0.25} = 16$ watts. A battery of 24 such cells would have $16 \times 24 = 384$ watts. For if arranged in one series the capability of the battery would be $\frac{(2 \times 24)^2}{0.25 \times 24} = 384$; or if arranged in 2 series of 12 each in multiple, the capability of the battery would be $\frac{(2 \times 12)^2}{\left(\frac{0.25}{2} \times 12\right)} = 384$, and so on for any symmetrical grouping of rows and series.

93 When a given small amount of activity is to be furnished by a voltaic battery, the first consideration is, of course, to obtain this activity with a maximum economy. The maximum economy may be either the maximum economy of operating the battery, or the maximum economy of installing it, which, of course, are entirely different.

The maximum economy of operation is obtained when the number of cells is such that the materials they consume, together with the interest, depreciation and attendance, on the whole plant, is a minimum. The maximum economy of installation is obtained when the number of cells employed that will satisfactorily perform the required activity is a minimum. If P, be the amount of this activity expressed in watts, then the minimum number of cells is $4P$, divided by the capability of each cell. Or the number of cells, $N = \frac{4P}{(e^2\ r)}$. In other words,

the maximum economy of first installation is reached when the capability of the battery is four times the activity.

Thus, if a battery were required to operate a sewing machine taking 12 watts, through a motor of 0.5 efficiency, requiring 24 watts, and if each cell of the battery to be used had an E. M. F. of 1 volt and an internal resistance of 0.125 ohm, its capability would be 8 watts, and the minimum number of cells required would be $\frac{4 \times 24}{8} = 12.$

This number of cells would be independent of the grouping adopted, for the same results would be obtained with 12 cells in a single series, two rows of six, three rows of four, four rows of three, six rows of two, or by all twelve cells in parallel. Practically, however, the arrangement would depend on the winding of the motor. If the motor were wound for six volts, then all the cells would be connected in one series. The E. M. F. of the battery would be 12 volts, its internal resistance 1.5 ohms, and its electrical capability $\frac{12 \times 12}{1.5} = 96$ watts. If the battery were placed on short-circuit it would therefore do work through its own resistance at the rate of 96 watts, which is four times the external activity or output required. On connecting with the motor, the current delivered at the required output would be 4 amperes. The drop in the battery would be $IR = 4 \times 1.5 = 6$ volts, or half the E. M. F., and the pressure remaining at terminals would be 6 volts. The external activity would be 24 watts, the internal activity 24 watts, the total activity in the circuit 48 watts or half

the capability of the battery, and the efficiency of the battery would be 0.5.

94. Minimum cost in battery installation satisfies the following six conditions:

(*1.*) The capability of the battery is four times the output.

(*2.*) The capability of the battery is twice its total activity.

(*3.*) The internal and external activities are equal.

(*4.*) The pressure at battery terminals is equal to the drop in the battery.

(*5.*) The efficiency of the battery is 0.5.

(*6.*) The current strength through each cell is half that which it would deliver on short-circuit.

95. The voltaic cell ranks high as an electric source for the production of comparatively constant E. M. F.'s. Ordinarily the E. M. F. of a voltaic cell, as usually constructed, is variable, depending as it does upon a number of circumstances such as temperature, strength of solution, purity of plates and exciting liquid, atmospheric pressure, and activity of the circuit. Yet if certain precautions are taken in the preparation and use of voltaic cells, they can be made to produce a very uniform E. M. F. The E. M. F. of a dynamo machine can only remain uniform when the speed of rotation is maintained constant and the field magnets retain a constant strength, conditions which are frequently difficult or expensive to maintain, when only a small amount of power is desired. On the contrary, in the case of the voltaic cell, if fairly uniform conditions are assured, the value of the E. M. F. will remain very nearly constant. So true is this that the legal value of the unit of E. M. F.,

the volt, has been decided as being a definite fraction of that furnished by a particular form of standard cell known as a Clark standard, at a definite temperature, ($\frac{1}{1.434}$th part at 15° C.)

96. The following fields of usefulness exist at present for the voltaic battery:

(*1.*) As a limited source of power. This we have seen is limited by the expense of materials and of operation. The limit is apparently reached in practice at the power required to drive a sewing machine, which at ordinary moderate speeds, as already mentioned, is about twelve watts. Allowing an efficiency of 0.5 in the small driving motor, the delivery of power from the battery becomes about 24 watts. Beyond this amount of power, the expenses of installing and maintaining a battery is, even with the best existing types, generally regarded as prohibitory.

(*2.*) For signalling purposes, as in telegraphy, telephony, annunciators, etc. Here the amount of work required is usually very small. The amount of energy delivered by a battery of 100 cells to a telegraph line being usually about three watts. In all large telegraph stations, dynamos, or storage cells charged by dynamos, are being generally employed.

(*3.*) For testing purposes, as, for example, in furnishing a uniform E. M. F.

(*4.*) For electroplating; although here also, on all but the smallest scale of operation, the dynamo has come into use.

(*5.*) For electro-therapeutic purposes, owing to the portability of a voltaic battery.

It will be seen, therefore, that the principal uses for voltaic cells are for testing, and for domestic service

where a current from dynamos cannot readily be obtained. This statement refers to the existing batteries which burn zinc. Should it become practically possible to consume carbon in a commercial voltaic battery and obtain an output approaching the theoretical amount, it might readily become much cheaper to produce electrical energy from batteries than from dynamos, and the use of the steam engine, as the prime source of electric power, might be superseded.

SYLLABUS.

The source of energy in a voltaic cell is the chemical potential energy of the plates of the electrolyte.

Voltaic batteries, as at present constructed, can never compete with steam-driven dynamos for the delivery of large electric currents. For small powers, however, voltaic batteries possess many advantages over dynamos.

The electrical capability of a cell, or the amount of power the cell is capable of furnishing when placed on short circuit, is equal to the square of the E. M. F. of the cell divided by its resistance.

The electric cell, when suitably constructed, ranks high as a source of extremely uniform E. M. F. In this respect it far surpasses the dynamo.

The legal value of the volt, the unit of E. M. F., is taken as that furnished by a particular form of Clark standard cell, at a fixed temperature.

The following are the principal fields of usefulness for the voltaic cell, viz.:

(*1.*) As a limited source of power. (*2.*) For signalling purposes. (*3.*) For testing purposes. (*4.*) For electroplating. (*5.*) For electro-therapeutics.

No. 12.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

MAGNETOMOTIVE FORCE.

97. Surrounding every magnet there is a region of magnetic influence, technically known as the magnetic field. The region is permeated with what are frequently called *lines of magnetic force*, but which may be more accurately described as *magnetic flux-paths.*

Magnetic flux possesses the following properties, namely: (*1.*) A bar of iron when introduced into the flux becomes magnetized. (*2.*) A freely suspended magnetic needle brought into the flux, comes to rest in a definite position. (*3.*) An electric conductor moved across the flux paths has an electromotive force developed in it.

The exact nature of magnetic flux is not understood, but it appears to be attended by a stress in the ether.

98. A convention is employed as to the assumed direction of the magnetic flux, similar to that employed in the case of electric flux; viz., the magnetic flux is assumed to issue from the magnet, as shown in **Fig. 36,** at its positive or north, *i. e.*, north-seeking pole N,

(that which tends to point northwards if the needle be free to move), and, after passing through the region around the

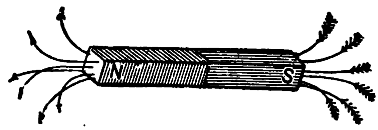

FIG. 36.—DIAGRAM OF ASSUMED DIRECTION OF FLUX-PATHS IN A MAGNETIC CIRCUIT.

magnet, to re-enter it at its negative or south-seeking pole, s, thus corresponding with the direction of the electric flux, which is assumed to leave an electric source

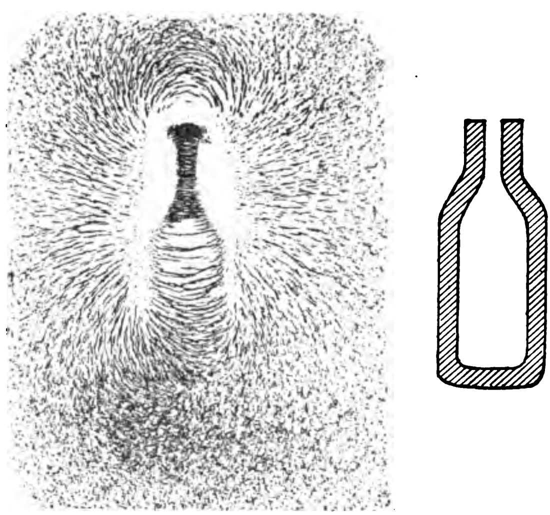

FIG. 37.—PERMANENT MAGNET AND FLUX-PATHS SURROUNDING IT, AS INDICATED BY IRON FILINGS ON PLATE LAID FLAT ON MAGNET.

at its positive pole and re-enter it after having passed through the circuit at its negative pole.

99. Figs. 37 and 38 represent the assumed direction of the magnetic flux in the case of a magnet of the form shown, placed in Fig. 37, with its greatest length horizontal to the plate, and in Fig. 38, with its greatest length vertical to the plate. A careful inspection of these figures will show that the poles are not by any means concentrated at points situated at the extremities of the bar, but are distributed over a considerable area.

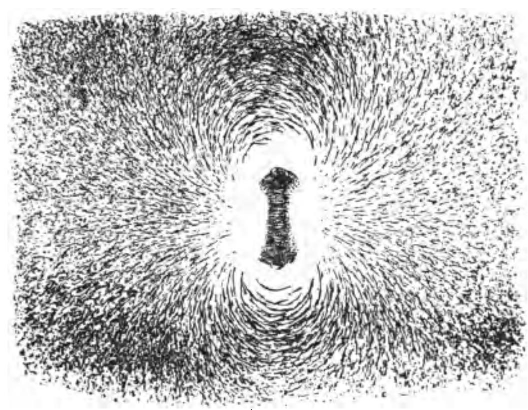

FIG. 38.—FLUX-PATHS SURROUNDING MAGNET POLES AS INDICATED BY IRON FILINGS ON PLATE LAID UPON THE POLAR EXTREMITIES.

Magnetic figures may be obtained by suitably supporting a sheet of paper over a magnet, sprinkling iron filings upon the paper, and then gently tapping it so as to enable the filings to arrange themselves under the influence of the magnetic forces.

100. The preceding figures show the flux-paths only in the immediate vicinity of the magnet, being limited by the size of the sheet of paper employed. In reality the magnetic flux exists for indefinitely great distances

around the magnet, but at distances exceeding a few inches becomes so weakened that its detection requires the use of comparatively delicate apparatus.

The magnetic flux-paths, around any bar magnet, as they may be traced either by iron filings, or by an *exploring magnetic needle*, (*i. e.*, a suspended magnetic needle which assumes the direction of the flux at the point it occupies) show that the flux paths coincide with the stream-lines which would be produced by a tube filled with and surrounded by an incompressible liquid, such as water, if a force pump within the tube, drove the liquid out at one end of the tube and sucked it in at the other end. In the case of a magnet, the magnetic stream-lines, as already remarked, are assumed to pass out from the north pole and re-enter at the south pole. (The force which causes this flux, corresponding to the force driving the pump producing the liquid flux, is called the *magnetomotive force*, usually abbreviated M. M. F.) The M. M. F., in the case of the magnetic circuit, corresponds to the E. M. F. in the case of an electric circuit.

We have seen that in the electric circuit, no flux, *i.e.*, no current can exist without the establishment of an E. M. F. in the circuit. Similarly, in the magnetic circuit, no flux can exist without the establishment of a M. M. F. in the circuit.

The unit of magnetomotive force is called the gilbert, from Dr. Gilbert of Colchester, a famous early authority on magnetism, (1600 A.D)

101. There are two distinct varieties of M. M. F.; namely, the *permanent*, or that naturally existing in certain kinds of matter, notably in iron, nickel, cobalt; and the *transient*, or that produced in the neighborhood

of a conductor by the passage through it of an electric current. When an electric current circulates through a conductor, a certain distribution of flux is produced in the region surrounding the conductor. If, however, this region is occupied by iron, the amount of flux produced is enormously increased, and the only explanation consistent with the facts is that there is a source of M. M. F. in the magnetized iron as well as in the electric current;

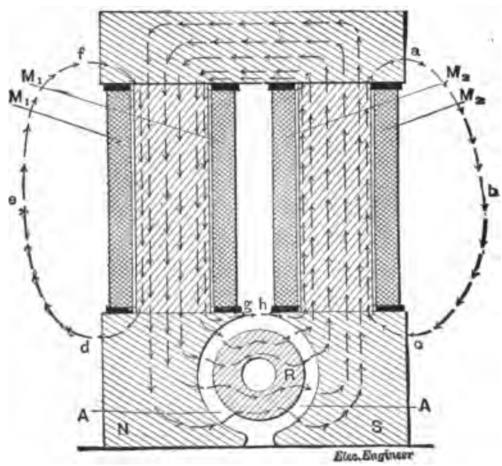

FIG. 39.—SECTION OF A COMMON TYPE OF DYNAMO WITH MAGNETIC CIRCUIT INDICATED.

for, if the iron be hard, its magnetic condition will in a great measure persist after the magnetizing current has ceased to flow, in which case the iron must be regarded as the seat of a permanent M. M. F.

102. In nearly all practical magnetic circuits, the magnetic flux passes, for the greater part of its path, through iron. Thus in Fig. 39 is shown an ordinary bi-polar dynamo in which the magnetic circuit is

indicated by the dotted lines. Here the path through the field magnets is entirely of iron; through the armature largely of iron, and through the interpolar spaces between the armature and the surrounding pole faces, A A, through air.

In the multipolar dynamo shown in Fig. 40, the magnetic circuits passing through each pole, divide, passing as before through circuits, indicated by the dotted lines,

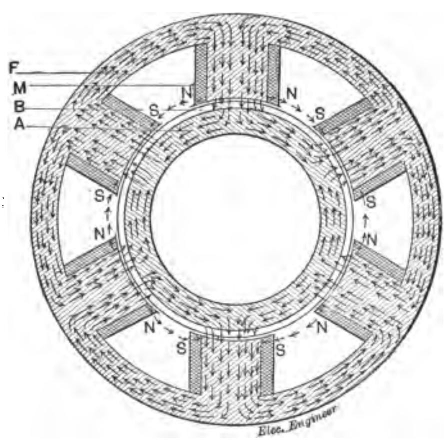

FIG. 40.—DIAGRAMMATIC SECTION OF A SEXTIPOLAR DYNAMO, SHOWING THE MAGNETIC CIRCUITS AND GENERAL ARRANGEMENT OF FLUX DISTRIBUTION UNDER THE EXCITING-COIL M. M. F.'S.

lying mainly through iron, as at F, but partially through air, as at B.

The M. M. F. which drives the magnetic flux through any circuit is dependent on two factors; namely, the current strength passing through the magnetizing coils, and the number of turns of wire in these coils. This product is generally expressed in ampere-turns.

103. The unit of M. M. F. is the gilbert. It is the M. M. F. produced by $\frac{10}{4\pi}$ or approximately 0.7958 ampere-turn. It is only necessary, therefore, to multiply the number of ampere-turns on the field magnets of a dynamo machine by $\frac{1}{0.7958} = 1.257$, to obtain the M. M. F. expressed in gilberts. For example, a particular 10 K. W. dynamo of the bi-polar type has two field coils, one on each magnet. The total number of turns on these two coils is 2,100, and the current, which circulates through these coils at full load, is 2 amperes. The M. M. F. in ampere-turns is, therefore, 4,200, and in gilberts, 5,279.

104. While magnetomotive forces may be conveniently and accurately expressed in ampere-turns, the C. G. S. system of International measures requires that the unit of M. M. F. should differ by a numerical factor. In dealing with M. M. F.'s, it is commonly convenient to express their values in ampere-turns, but for purposes of computation, and for simplicity of reasoning, it is usually advantageous to employ the more fundamental and scientific unit, the gilbert.

105. Magnetomotive force, like electromotive force, possesses direction. That is, several M. M. F.'s may oppose or aid one another, the resultant M. M. F. being their geometrical sum, precisely like the case of various E. M. F.'s acting in an electric circuit. Thus the M. M. F.'s produced in the magnetic circuit of a dynamo, by two separate magnetizing coils, as shown in Fig. 39, will be additive, if the exciting coils are magnetized by currents in the same direction, and subtractive if the coils are magnetized in opposite directions.

The M. M. F. produced by a current of 100 amperes, passing through a single loop of conducting wire, would be 100 ampere-turns, or 125.7 gilberts, whether that turn of wire were alone or whether it were associated with other turns of wire in a coil, and whether it surrounded iron or not; but the flux, which that M. M. F. would produce, would vary very greatly in these different cases.

SYLLABUS.

A magnetic field, or a region permeated by magnetic flux, accompanies every magnet or every conductor conveying an electric current.

A magnetic field produces, or is accompanied by, a stress in the ether, which may manifest its presence in a variety of ways.

The density of the magnetic flux in any field is greater near the magnet than at distances from the magnet, and is usually at its maximum value in the neighborhood of the magnetic poles.

The unit of M. M. F. is termed the gilbert, and is equal to the M. M. F. produced by 0.7958 ampere-turn.

All magnetic flux, *i.e.*, all magnetism, is produced by M. M. F., just as all electric flux or current is produced by E. M. F.

M. M. F.'s, like E. M. F.'s, possess direction, so that several M. M. F.'s may oppose or aid one an other; that is, their general effect is either subtractive or additive.

No. 13.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

MAGNETIC RELUCTANCE.

106. The magnetic flux produced in any magnetic circuit by a given M. M. F. depends upon the magnetic resistance of the circuit. In this respect magnetic resistance is similar to the resistance which an electric circuit offers to the passage of an electric flux under the influence of a given E. M. F. Magnetic resistance is called *reluctance*. In order to increase the magnetic flux under given M. M. F. it is only necessary to decrease the reluctance of the circuit.

The following differences exist between magnetic reluctance and electric resistance; viz.,

(*1.*) Unlike the resistance in an electric circuit, the reluctance of masses of similar dimensions of nearly all materials, except iron and the magnetic metals, is practically the same as that of air.

(*2.*) The electric flux can be confined to a definite path, usually a wire, while the magnetic flux, in general, cannot. The reason is that an electric conductor can be

readily insulated, whereas there is no known insulator for the magnetic flux. The magnetic flux which proceeds from the north-seeking pole of a magnetic source passes through numerous diverging paths, re-entering the magnet at its south-seeking pole.

(*3*.) In the case of an electric circuit, where a long single wire sustains a steady current, the current density is the same at all points in any cross-section of the wire; in the case of a magnetic circuit, the flux density, in general, varies at different points in the cross-section of the circuit, and decreases as we recede from the poles.

107. As the specific resistance of a conductor is best defined under the term resistivity; namely, the resistance offered by a unit volume, or a unit cube of a material taken between its opposite faces, so the specific magnetic reluctance of a substance is best defined under the term *reluctivity*, or the magnetic reluctance of a unit cube, *i. e.*, of a cubic centimetre, taken between parallel faces. The magnetic reluctivity of vacuum is taken as unity, and the reluctivity of air, copper, wood and nearly all substances except the magnetic metals, does not differ appreciably from the reluctivity of vacuum. The reluctivity of the magnetic metals varies with the density of the flux traversing them.

Fig. 41 shows curves of reluctivity in various samples of iron and steel for different flux densities. Thus the lowest curve No. VII., representing soft annealed Norway iron, shows, for example, a reluctivity of 0.7 thousandth, *i. e.*, $\frac{1}{1429}$th that of air, at a flux density of 10 kilogausses. In other words each cubic centimetre of this iron subjected to a flux intensity of $\mathfrak{B} = 10{,}000$ gausses,

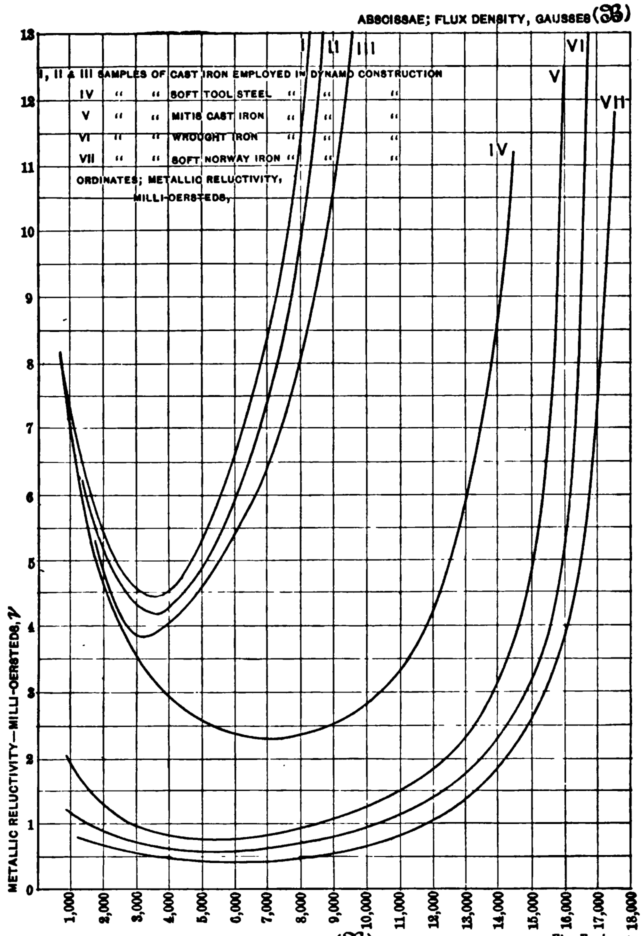

FIG. 41.

Curves of reluctivity in iron and steel in relation to flux density, from measurements by Kennelly.

offers, between opposed faces, a reluctance of 0.0007 oersted.

108. There are three varieties of magnetic circuits; viz.,

(*1.*) The *non-ferric* circuit, where the magnetic circuit is completed through air or other non-magnetic materials. Such would be the magnetic circuit of a hollow coil of wire.

(*2.*) The *ferric* circuit, where the magnetic circuit is entirely completed through iron, as in the case of an

FIG. 42

Non-ferric magnetic circuit. Coils of insulated copper wire on rubber cylinders distributing a magnetic circuit through air, wood and hard rubber.

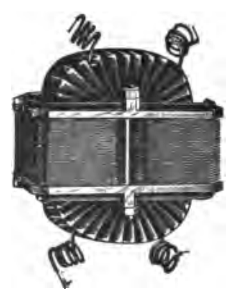

FIG. 43.

Ferric magnetic circuit, an alternating current transformer. With the exception of "leakage" all the flux passes through iron.

iron ring wrapped with wire, or an electro-magnet with the keeper pressed upon its poles.

(*3.*) The *aero-ferric* circuit, in which the circuit lies partly through air and partly through iron. To this class of circuit belong the great majority of dynamos and electro-magnetic apparatus.

Fig. 42 represents a type of non-ferric circuit. Fig.

43 represents a type of ferric circuit; and, Fig. 44, a type of aero-ferric circuit.

109. The reluctances of practical magnetic circuits are very difficult to compute, owing to the variation of the cross-section of the magnetic circuit at different points. Fig. 45, however, shows a particular case of non-ferric magnetic circuit, which is amenable to very simple treatment.

If in the anchor ring of wood, copper, or other non-magnetic material, uniformly wrapped with wire, as

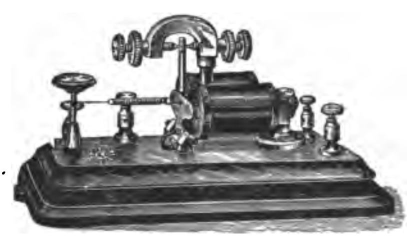

FIG. 44.
Aero-fe.ric circuit; a telegraph relay. Magnetic circuit through cores, yoke and keeper of magnets and air gaps at poles.

shown in Fig. 45, the mean circumference of the coil is 50 cms., and the cross-section of the interior of the coil is five square centimetres, then the reluctance of the magnet circuit, which will be confined entirely to the space within the winding, will be approximately $\frac{50}{5} = 10$ oersteds. All the flux paths in this case will be circular, and there will be no magnetic flux outside the winding. A compass-needle, therefore, held near the ring, provided the ring be uniformly wrapped, will fail to show whether the current is flowing through the winding or not. This

is the only known case in which magnetic flux can be readily confined to a determinate path.

110. If the core of the preceding ring be replaced by soft iron, then the reluctance of the circuit may be 1,000 times less, and, consequently, the magnetic flux in the circuit a thousand times greater. Such a ring, although carrying a powerful magnetic flux, would still evidence no external magnetism, but if a saw-cut be made through the ring at any point, as in Fig. 46, the opposite faces of this gap would show opposite polarity, and the magnetic circuit would then become of the aero-

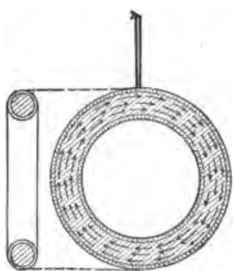

FIG. 45.

Principal sections of closed circular coil and its magnetic circuit. Core of wood or iron.

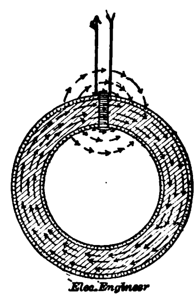

FIG. 46.

Diagram of aero-ferric magnetic circuit. Anchor ring iron core with air-gap.

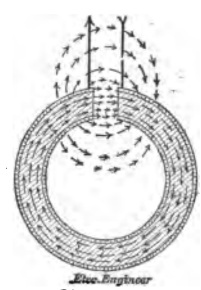

FIG. 47.

Diagram of aero-ferric magnetic circuit. Anchor ring iron core with wider air-gap.

ferric type, with flux lines proceding through the surrounding air. At the same time, the magnetic reluctance of the circuit is markedly increased; thus if the saw-cut is one millimetre in width, and its area of cross-section five square centimetres, the increase of reluctance thus added to the previous ferric circuit would be $\frac{0.1}{5} =$ 0.02 oersted approximately. The true value of the reluctance would be somewhat less than this owing to the

slight diffusion of the flux beyond the limits of the air gap as shown, thereby sensibly increasing the effective cross-section of the air gap.

111. If the width of the air gap be increased, as shown in Fig. 47, then the increase in the reluctance of the circuit will produce a still more marked variation in the amount of magnetic flux, and the diffusion of the lines will be more marked. Owing to this diffusion, the reluctance of the air gap will be increased,

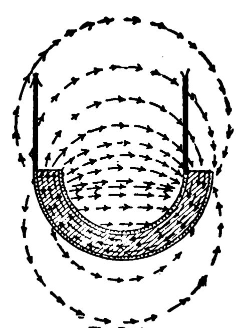

Fig. 48.
Diagram of aero-ferric circuit of half ring.

but not in proportion to its length, the average cross-section being greater than five square centimetres.

If the air gap be still further widened, as in Fig. 48, the same effects are still more markedly produced until the total flux in the magnetic circuit may be only a small fraction of that existing in the original case. But this weaker magnetic flux may have far more powerful influence upon neighboring magnets, owing to the external diffusion of the flux paths, as shown.

112. It is a curious fact that although the reluctivity of all non-magnetic substances is practically the same as that of the air-pump vacuum, yet the reluctivity of different specimens of iron is subject to marked variations. An exceedingly small percentage of carbon in iron may greatly increase its reluctivity. As a rule the softer and purer the iron, the lower its reluctivity. Nickel is, perhaps, the only ingredient which forms an exception to this rule.

Syllabus.

The reluctivity of a magnetic circuit is the resistance it offers to the passage of the magnetic flux through it under a given M. M. F.

Specific reluctance, or reluctivity of a substance, is the reluctance offered by a cubic centimetre of the substance between opposite faces.

Reluctance is measured in units called oersteds. An oersted is the reluctance offered by a cubic centimetre of air-pump vacuum.

Magnetic circuits are of three kinds; non-ferric, ferric, and aero-ferric.

The reluctivity of iron is much less than that of air, but varies with the flux density; at first diminishing and afterwards increasing with the density.

A closed circular coil is the only form of magnetic circuit in which the flux is strictly limited to a definite path. In aero-ferric circuits, the diffusion of the magnetic flux will be greater as the portion of the circuit occupied by air is increased.

No. 14.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

MAGNETIC FLUX.

113. The magnetic flux in any magnetic circuit is directly proportional to the M. M. F. acting on that circuit and inversely proportional to its reluctance; or, since the unit of magnetic flux is the weber, the unit of M. M. F. the gilbert, and the unit of magnetic reluctance the oersted, we have the general expression,

$$\text{webers} = \frac{\text{gilberts}}{\text{oersteds}} \text{ or, } \Phi = \frac{\mathfrak{F}}{\mathfrak{R}},$$

this corresponding with the expression given by Ohm's electric circuit law,

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}} \text{ or, } I = \frac{E}{R}.$$

Here $\mathfrak{F}$, is the existing international symbol for Magnetomotive Force, similarly, $\mathfrak{R}$, denotes Reluctance, and the Φ is the symbol for Flux.

In either of the above equations, any two of the three

independent quantities being known, the remaining one can be calculated. Thus,

$$\text{gilberts} = \text{webers} \times \text{oersteds}\,;\ \mathcal{F} = \Phi\,\mathcal{R}.$$

Or,

$$\text{oersteds} = \frac{\text{gilberts}}{\text{webers}}\,;\ \mathcal{R} = \frac{\mathcal{F}}{\Phi}.$$

114. In practical magnetic circuits it is often a matter of considerable importance to be able to calculate the magnetic flux. In order to do this, in accordance with the preceding principles, it is only necessary to determine the values of the M. M. F. and the reluctance; for, as is evident, there are but two ways in which the value of the magnetic flux in any circuit can be varied; namely, by altering the value of either of these quantities.

The value of the M. M. F. is most readily increased by increasing the strength of the exciting current. We will now show, by some practical examples, how the preceding equations may be applied in the determination of magnetic flux in a circuit.

115. *Case 1*—the simple case of an anchor ring, of soft Norway iron, wound with insulated wire: We commence with this case, because, as we have already pointed out, this type of circuit, if properly constructed, possesses no magnetic leakage. The area of cross-section of the iron ring, of dimensions shown in Fig. 49, is 3.1416 square inches = 20.268 square centimetres, and the mean length of the circuit, or the mean circumference of the ring, is 37.7 inches = 95.74 centimetres. If the total flux, which it is desired to send through this circuit, be 350 kilowebers, it is required to

determine the M. M. F. which must be applied to the ring in order to produce this flux.

The reluctance of the circuit is obtained as follows: When 350,000 webers are transmitted uniformly through a circuit, the cross-section of which is 20.268 sq. cms., the flux density will be $\frac{350{,}000}{20.268} = 17{,}270$ gausses $= 17.27$ kilogausses; *i.e.*, 17.27 kilowebers to the square centimetre. Referring to the diagram, Fig. 41, it will be seen on Curve No. VII., that, at this density, the reluctance of a cubic centimetre of Norway iron is by measurement, 9.2

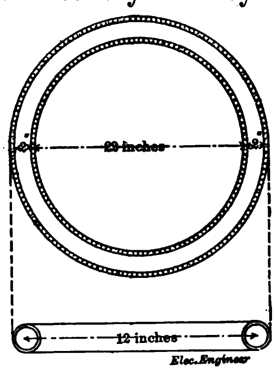

FIG. 49.

Ferric Magnetic Circuit. Norway iron ring uniformly wound with wire in turns. Mean circumference 37.7 in. = 95.74 cms. Cross-section of ring 3.1416 sq. in. = 20.268 sq cms.

millioersteds. The reluctance of the circuit is, therefore, $\frac{95.74}{20.268} \times 9.2 = 43.46$ millioersteds $= 0.04346$ oersted. Inserting this reluctance in the equation $\mathcal{F} = \Phi\,\mathcal{R}$, we have the required M. M. F. $= 350{,}000 \times 0.04346 = 15{,}210$ gilberts. Since one gilbert is 0.8 ampere-turn approximately, the required number of ampere-turns is $15{,}210 \times 0.8 = 12{,}170$, or more nearly $15{,}210 \times 0.7958 = 12{,}110$ ampere-turns. If now the winding of the ring be composed of 1,500 turns of insulated wire, the cur-

rent in each turn must be $\frac{12,110}{1,500} = 8.074$ amperes, and this is the required exciting current.

116. *Case 2.*—Taking now the case of an aero-ferric circuit, in which part of the flux-paths lie through air, say, an electromagnet, as shown in Fig. 50, let us first assume that the leakage is sufficiently small to be negligible; that the air-gap in the circuit is fixed; *i.e.*, that the keeper cannot move up to the poles of the magnet; and that the iron in the electromagnet and keeper is ordinary, soft, wrought iron. Then if a total flux of

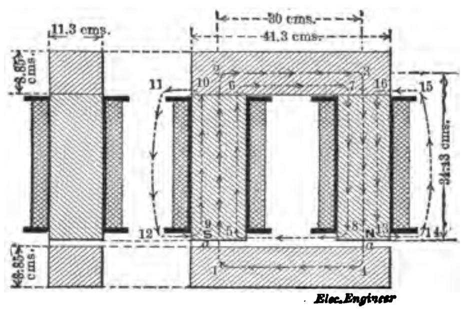

FIG. 50.

Electromagnet of wrought iron, æro-ferric circuit. Air gaps ½ in. = 1.27 cm. Mean length of magnetic circuit 140.24 cms. Cross-section of magnetic circuit 25 sq. cms.

300 kilowebers is to be sent through the circuit, it is required to find the excitation necessary for the magnet to produce this flux. Here, as before, we have to find the total reluctance of the circuit. Taking first the air reluctance, each air-gap, *a*, *a*, has a length of half an inch = 1.27 cms.; and a cross-section of 3.875 square inches = 25 square cms. The reluctance of each air-gap is, therefore, $\frac{1.27}{25} \times 1 = 0.0508$ oersted, since the reluctivity of air is unity. Since they are placed in series, the reluctance of both air gaps is, therefore, 0.1016 oersted.

If the cross-section of the cores, yoke and keeper is uniformly 25 square cms., the flux density will be uniformly $\frac{300}{25} = 12$ kilogausses. Referring to Fig. 41, the reluctance of wrought iron at this density may be taken as approximately 1.316 millioersteds in a cubic centimetre. With this reluctivity the reluctance of the iron in the circuit will be $\frac{137.7}{25} \times 1.316 = 7.248$ millioersteds, or 0.007248 oersted, since the mean path in the iron has a length of 137.7 cms. Adding the reluctance of the air,

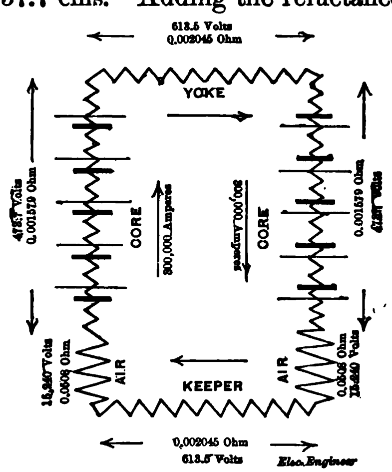

FIG. 51.

Electric Circuit Analogue of Æro-Ferric Circuit in Fig. 50. Without Leakage.

we have, for the total reluctance in the circuit, 0.108848 oersted. Consequently, the M. M. F. required will be $300{,}000 \times 0.108848 = 32{,}654$ gilberts $= 25{,}980$ ampere turns, and, should the number of turns on both coils together be 5,000, the required exciting current is 5.196 amperes.

The electric circuit corresponding to this case is shown in Fig. 51. Here two equal E. M. F.'s in series, each of

16,277 volts, act on a circuit of 0.108848 ohm resistance. The drop of magnetic potential in each air-gap is 15,240 gilberts, while the drop of potential in each core is 453.7 gilberts.

Owing to the fact that the air round the magnet is not a magnetic insulator, the preceding calculation cannot be regarded as strictly correct, since we have left all external or leakage flux out of consideration. It is evident that with ferric circuits, in which the flux density is not excessive, that is say, in which the reluctivity of the circuit is far less than that of the external air, the leakage will be small, even though the arrangement of the circuit differs materially from the anchor ring type with uniform winding. As the air-gaps in a circuit become wider and more numerous, the leakage flux bears a larger proportion to the total, and the circuit becomes less amenable to simple numerical treatment, owing to the complexity of the various branch circuits, and the difficulty of computing their local reluctances. This condition renders the calculation of practical magnetic circuits much more tedious and difficult than that of ordinary electric circuits. Most dynamo or motor magnetic circuits can, however, be computed with a degree of approximation sufficient for practical purposes in design. The following case illustrates the method of procedure.

117. *Case 3.*—Let the magnet, shown in Fig. 50, possess a leakage flux of 20 per cent. through the path 5, 6, 7, 8. That is to say, for every 100 webers passing through the cores and yoke, 20 pass through the air between the poles, and only 80 pass through the keeper. Required the M. M. F. to send 300 kilowebers through the keeper, as before.

The flux through the cores and yoke will now be $\frac{300}{0.8}$ $= 375$ kilowebers, at a mean density of $\frac{375}{25} = 15$ kilogausses. By reference to Fig. 41, the reluctance of a cubic centimetre of wrought iron for this density is 3.077 millioersteds. Of the 25 square cms. of cross-section in the cores and yoke, only 20 can now be considered as carrying the keeper flux, the remaining five square cms. being allotted to the leakage flux. Since the mean length of circuit

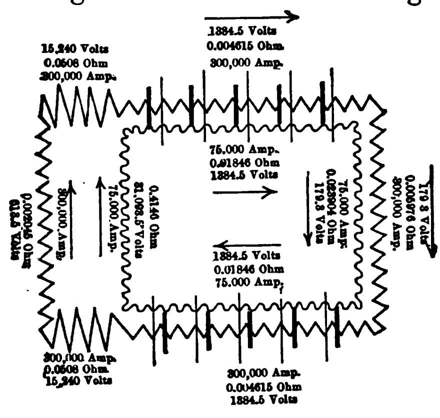

FIG. 52.

Electric Circuit Analogue of Æro-Ferric Circuit in Fig. 50. With Leakage.

through cores and yoke is 98.85 cms., their reluctance in the main or keeper circuit is $\frac{98.85}{20} \times 3.077 = 15.21$ millioersteds = ... 0.01521 oersted.

The reluctivity of the keeper remains at 1.316 millioersteds, as its flux density is 12 kilogausses. The keeper reluctance is, therefore, $\frac{38.85}{25} \times 1.316$ $= 2.045$ millioersteds = ...0.002045 "

The two air-gap reluctances remain as before at........................0.1016 "

So that total reluctance in keeper, etc. = 0.118855 oersted.

The M. M. F. necessary to force 300 kilowebers through this circuit is $300{,}000 \times 0.118855 = 35{,}656.5$ gilberts $= 28{,}370$ ampere-turns, or 14,185 ampere-turns to each spool, requiring a current strength of 5.674 amperes.

The corresponding electric circuit is shown in Fig. 52. It will be observed that while the drop of pressure in the air-gaps is 15,240 gilberts, as before, the drop in the cores and yoke has been increased by the introduction of leakage from 1560.9 gilberts to 4562 gilberts.

The reluctance of the leakage path between the poles is observed to be 0.4146 oersted. It is evident, therefore, that, whenever the reluctance of leakage paths can be computed, the distribution and amount of leakage flux can be determined.

SYLLABUS.

In any magnetic circuit the webers = the gilberts divided by the oersteds. Corresponding to Ohm's law in the electric circuit, the amperes = the volts divided by the ohms

Given, any two of the three quantities in either of the above formulæ, the value of the other quantities may be calculated.

The value of the magnetic flux in any circuit may be increased either by increasing the M. M. F. or by decreasing the reluctance. The M. M. F. may be increased by increasing the number of ampere-turns in the magnetizing circuit.

In the design of electromagnets, the reluctance can be varied either by varying the dimensions of the iron circuit, or by varying the character of the iron employed.

No. 15.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

ELECTROMAGNETS.

---

118. (An electromagnet is a magnet produced by the passage of an electric current through a coil of wire linked with a magnetic circuit.) The name electromagnet is practically limited, however, to cases where the core, placed inside the helix, is made of soft iron. Under these circumstances the core acquires the properties of an electromagnet, and, disregarding residual magnetism, loses these properties when the current ceases.

119. When a bar of hard or soft iron is brought into a magnetic flux, an alignment of its molecules, or ultimate particles, is supposed to take place. This alignment is more readily produced in soft iron than in hardened iron, as, indeed, would be supposed, bearing in mind, the characteristic property of hard iron which opposes any deformation or change of shape. When the prime M. M. F. ceases to act on the iron, as would occur either by withdrawing the iron core from the prime flux, or by causing the magnetizing current to cease, the freedom of

movement naturally possessed by the molecules of soft iron, permit them readily to lose their new alignment, and the structural M. M. F. is dissipated with the resumption of practically its previous condition. In the case of hardened steel, however, the resistance which the molecules offer to change of position, enables the structural M. M. F. to be largely retained. For this reason the magnetism produced in soft iron is sometimes called *temporary magnetism*, and that in hard steel, *permanent magnetism*.

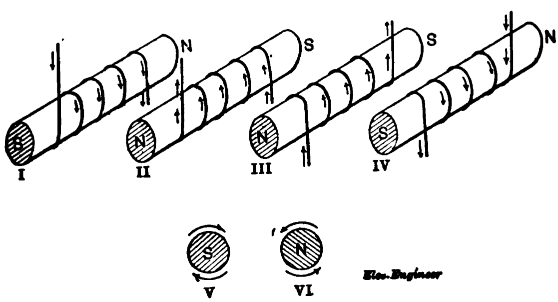

FIG. 53.

Indicating the direction of magnetization in an iron bar as dependent on the direction of winding and of current.

120. When an electric current passes through a wire, an M. M. F. is established around the wire. This M. M. F. produces a distribution of flux in cylinders concentric to the wire, the intensity diminishing directly with the distance from the axis of the wire. The direction of this flux, relative to the direction of the current in the wire, being as shown in Fig. 53. When the wire is bent into a circular loop, it is evident that the M. M. F. produced by the loop is directed either all upwards or all downwards through the loop, so that the direction of the flux depends on the direction of the current. The

M. M. F. from a helix, which has a succession of turns, is also directed through the helix in one direction or the other, both according to the direction of the current and to the direction of the winding.

121. Magnets may be divided into different classes according to the character of the work they are called upon to perform; namely,

(*1.*) Tractive magnets; and,

(*2.*) Portative magnets.

A tractive magnet is one designed to exert a pull at a distance. A portative magnet is one designed to hold or support heavy weights attached to its armature, when the latter is at rest upon the poles.

122. An electromagnet is designed to produce a certain traction or pull on its keeper. This pull may be exerted either when the keeper is at a distance; that is, separated by an air-gap; or, when the keeper is actually brought into contact with the polar surfaces. In most practical cases, however, the attractive force is brought to bear between two parallel surfaces, usually called the *polar surfaces* across which the flux passes perpendicularly, as shown in Fig. 54. Under these circumstances, every square centimetre of opposed polar surfaces attracts the other with a force of $\frac{\mathcal{B}^2}{8\pi}$ dynes, where $\mathcal{B}$ is expressed in gausses, so that if the intensity is everywhere the same across the surfaces A, B, C and D, E, F, the total force of attraction between the surfaces will be $S \times \frac{\mathcal{B}^2}{8\pi}$ dynes. S being the area of polar surface in square cms.

123. If the flux does not possess the same value at different portions of the polar surfaces, then the active surface must be divided into a sufficient number of elements to permit the flux density to be considered uniform over each element, when the separate forces of each element can be determined, and their sum will be the total force on the whole surface. So far as the attractive power of a magnet is concerned, the total value of the flux is of secondary importance; it is the distri-

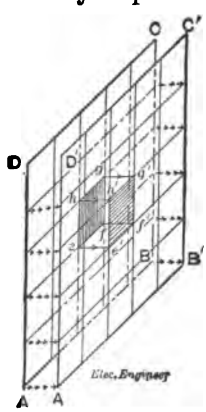

FIG. 54.
Flux normal to opposed plane parallel polar surfaces.

bution of the intensity of the flux at the active surfaces, in gausses, which is of primary importance. In soft Norway iron, the flux intensity can hardly be maintained above 19 kilogausses. The attraction between opposed surfaces of one square cm. in area traversed perpendicularly by 19 kilowebers, will be, therefore,

$$\frac{19{,}000 \times 19{,}000}{25.133} = 14{,}360{,}000 \text{ dynes,}$$

and, since one dyne equals 1.0203 milligrammes weight,

at Washington, this force represents 14,658 grammes, or 32.31 pounds weight, at Washington, per square centimetre of active polar surface (208.4 pounds per square inch).

124. In Fig. 40 on page 94, a sextipolar dynamo is represented in cross-section. Since flux passes into, or out of, the armature beneath each polar surface, each magnet core may be said to attract the armature, with a force that can be readily computed, to at least a fair degree of approximation, when the elements of the magnetic circuit are known.

For example, suppose that in each of the six magnetic circuits shown, the useful flux, *i.e.*, the flux passing through the armature core, is two megawebers. Then four megawebers will enter or leave the armature under each pole-piece. If the surface of each pole-piece is 200 square inches, *i.e.*, 1,293 square cms., the mean intensity in the air-gap and polar surfaces will be

$$\frac{4,000,000}{1,293} = 3,094 \text{ gausses.}$$

Assuming that this intensity is uniform over the surfaces, the tractive force, per square centimetre, exerted between pole and armature will be

$$\frac{3,094 \times 3,094}{25.133} = 380,900 \text{ dynes} = 388.5 \text{ grammes weight,}$$

and, since there are 1,293 square cms. opposed and active. the total force will be

$388.5 \times 1,293 = 502,300$ gms. weight $= 1,108$ lbs. weight. As the armature revolves, therefore, its iron core will be pulled upon outwards opposite each pole, with a force of about half a ton's weight, and the framework supporting the armature must be sufficiently strong to safely

support these forces, in addition to the ordinary centrifugal forces of rotation.

125. When a current passes through the armature, whether it be acting as a generator or motor, the effect of the M. M. F., set up by the current in the armature windings, is to superpose its flux upon that previously established by the field magnet M. M. F.'s. The combination of the two magnetic circuits is to destroy the symmetry of the flux distribution. For example, if the machine is receiving current as a motor, the effect of introducing the armature M. M. F.'s will be to so modify the flux distribution, shown in Fig. 40, as to increase the intensity in the air-gaps underneath all the left-hand edges of the polepieces (as each pole is regarded from the armature), and reduce the intensity at the opposite or right-hand edges. At the same time, the flux will be deflected from the perpendicular, and drawn through the air more or less obliquely. Under these circumstances tangential pulls will be exerted upon the armature, and each square centimetre on the left-hand edge will exert an increased pull in proportion to the square of the intensity, while the right-hand polar edge will exert a pull which is relaxed in corresponding measure. The resultant, or preponderating forces on the left-hand polar edges, will draw the armature round clockwise. This effect of the M. M. F. in the armature is called *armature reaction.* It is by reason of armature reaction that a motor pulls, and that a generator has to be pulled, while the pull is in all cases a distribution of

$$\frac{\mathcal{B}^2}{8\pi} \text{ dynes per square cm.}$$

over the opposed polar surfaces, under distortion from

the original symmetry of flux distribution. The fundamental law of tractive force in the electromagnet is consequently the fundamental law of rotary force in all electric dynamos and motors.

126. The portative force, which a magnet can exert, may readily reach 200 lbs. weight per square inch of active polar surface when the poles are of soft iron. It should, therefore, be the object, when designing a ferric magnetic circuit for simply portative purposes, to magnetically saturate the polar surfaces as nearly as possible, and not allow the iron to become equally saturated at any other part of the circuit. For this reason it is usual to constrict the section of the iron at the poles. The length of the circuit is then reduced as far as possible, so as to only allow just room for the exciting coil. In this way a very small electro-magnet weighing a decigramme can be made to support 2,500 times its own weight, a magnet weighing 100 grammes, 600 times its own weight, and a multipolar magnet, weighing a ton, should be able to support about 500 times its own weight.

When a tractive magnet has to exert a definite pull, under a given M.M.F. upon its armature, across an air-gap, the design of the magnetic circuit has to be altered. It is found that the best area of polar surface to employ is that which makes the reluctance of the air equal to the reluctance of the iron. This rule ensures the best intensity in the polar surfaces assuming no leakage to exist. The influence of leakage calls for a reduction in the air reluctance.

127. When a tractive magnet has to alternately attract and release its armature in rapid succession, as, for example, in the case of a telegraph relay, the

armature has to be made very light, in order that its inertia may not unduly increase the magnetic forces to be exerted.

An ordinary Western Union, neutral relay of 140 ohms resistance, has about 7,500 turns of wire, and, when excited by a steady current of 25 milliamperes, *i.e.*, to a M. M. F. of 187.5 ampere-turns, or 235.8 gilberts, exerts a total pull upon the face of its armature amounting to about 78 grammes weight when the distance between poles and armature is 0.1 cm. The reluctance of its circuit is then about 0.25 oersted, and the flux, consequently, about 943 webers.

SYLLABUS.

When a bar of soft iron is submitted to the permeating action of a magnetic flux, its ultimate particles become aligned, and a structural M. M. F. is established in the bar. On the withdrawal of the permeating magnetic flux, the structural M. M. F. disappears, through instability. Hard iron or steel retains the structural M. M. F. in a greater or less degree.

The tractive force exerted between opposed plane parallel polar faces is $\frac{\mathcal{B}^2}{8\pi}$ dynes per square cm. of either, or 0.2567 $\mathcal{B}^2$ dynes per square inch, or 5.771×10^{-7} lbs. per square inch, $\mathcal{B}$ being expressed in gausses.

The electromagnetic rotary pull of a dynamo or motor is due to tractive forces set up between the armature and field poles represented locally by $\frac{\mathcal{B}^2}{8\pi}$ dynes per square cm. from point to point.

No. 16.

Electrical Engineering Leaflets,

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9

INTERMEDIATE GRADE.

INDUCED E. M. F.

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128. Whenever a conductor moves across a magnetic flux, or a magnetic flux moves across a conductor, an E. M. F. is generated in the conductor; or, generally, whenever relative motion exists between a conductor and magnetic flux whereby either crosses the other, an E. M. F. is generated in the conductor. The amount of this E. M. F. is dependent on the rate of cutting of flux, and will evidently vary both with the rapidity of motion of either the flux or the conductor and with the intensity of the flux.

129. The following varieties of induced E. M. F. come under the above general head; namely,

(*a.*) *Dynamo-electric induction*, where a conductor is moved across magnetic flux.

(*b.*) *Magneto-electric induction*, where magnetic flux is moved across a conductor by the motion of a magnet.

(*c.*) *Self-induction*, where magnetic flux generated by a circuit moves through the circuit.

(*d.*) *Mutual induction*, where magnetic flux generated by one circuit moves through a neighboring circuit.

130. Three cases may arise where E. M. F. is produced by the motion of a conductor through magnetic flux. First, where a conductor at right angles to the flux, moves in a direction at right angles to the flux. Second, where a conductor oblique to the flux, moves in a direction at right angles to the flux. Third, where a conductor, oblique to the flux, moves in a direction oblique to the flux. The last is the most

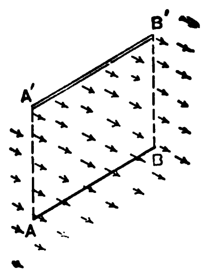

FIG. 55.

Conductor normal to flux, moving in direction normal to flux.

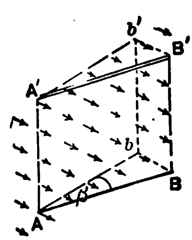

FIG. 56.

Conductor oblique to flux, moving in direction normal to flux.

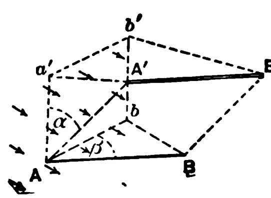

FIG. 57.

Conductor oblique to flux, moving in direction oblique to flux.

general case. Fig. 55 shows the first case, where a straight wire A B, of length l cms. moves through a uniform flux with a velocity of v cms. per second, which would carry it in one second to the position A′ B′. The flux cut through in this time would be that passing through the rectangle A B B′ A′. Here the total flux cut will be the area of this rectangle in sq. cms. multiplied by the intensity in gausses, and will vary with three quantities; viz., the length of the wire, the velocity of the motion, and the intensity of the flux.

131. In the second case, as shown in Fig. 56, where a conductor, oblique to the flux, is moved in a direction at right angles to it, the E. M. F. generated will depend on the amount of flux cut per second, and this will be equal to the flux passing through the rectangle A *b* *b'* A', where the side A *b*, is the virtual length of A B, that is, its length projected at right angles to the flux, and the projected length will evidently be smaller, the greater the angle β, or the greater the obliquity to the flux.

In the third case, shown in Fig. 57, both conductor and motion are oblique to the flux, and the E. M. F. in the conductor is proportional to the amount of flux contained in the rectangle A *b* *b'* *a'*, where A *b*, is the virtual or projected length of the conductor, and A *a'*, its virtual velocity.

The direction of the E. M. F. produced by the movement of a conductor across magnetic flux is, perhaps, most readily determined by *Fleming's hand rule*, in which, if the right hand be held as shown in Fig. 58, then if a conductor be moved in the direction in which the thumb points, and at right angles to the flux in the direction pointed out by the fore-finger, the E. M. F. generated will flow in the direction pointed out by the middle finger.

For example, if a straight wire 10 cms. long, make an angle of 30° with the flux, whose intensity is 500 gausses, and if it moves at a rate of 30 cms. per second, in a direction making an angle of 30° with the flux paths, the virtual length of the wire considered as lying across the flux would be $0.5 \times 10 = 5$ cms., and the virtual velocity of cutting the flux would be $0.5 \times 30 = 15$ cms. per second, so that the E. M. F. induced in the wire would be $5 \times 15 \times 500 = 37{,}500$ C. G. S. units, $= 375$ micro-

volts. This E. M. F. would be produced during the motion of the wire, but would cease the moment the wire came to rest.

132. In order that an induced E. M. F. may set up a current in a conductor, the circuit of that conductor must be closed; *i. e.*, it must form a conducting loop. If portions of this loop are cutting across mag-

FIG. 58.

netic flux, and thereby generating E. M. F. around the wire, the loop must either be enclosing more, or less, flux. If, therefore, in a conducting loop all the elementary portions be cutting through flux at an aggregate rate of 100 millions of webers per second, the flux added to, or subtracted from, the loop, will be 100 million webers per second, and the E. M. F. around the loop will be one volt.

In practice, when a dynamo armature is revolving in the magnetic flux established by its field magnets, the loops of conductors on the armature are having flux poured into them and then poured out of them successively; that is, are having E. M. F.'s induced in them in one direction as the flux is pouring in, and in the opposite direction as the flux is pouring out. For example, if the flux through a dynamo armature be 100 megawebers, and the revolving armature be so constructed that it poured all this flux through a loop upon the armature surface at a uniform rate during one-tenth of a second, the rate of pouring flux into the loop during that period, would be 1,000 megawebers per second, and the E. M. F. existing in the loop during the same period would be 10 volts. If then, during revolution, the armature continued emptying the loop at the same rate in the next tenth of a second, the E. M. F. in the loop during that period would be still 10 volts, but in the reverse direction.

133. All forms of dynamo electric machinery, that is, all forms of machinery for the generation or modification of E. M. F., are devices whereby magnetic flux is poured into and emptied out of conducting loops. The underlying principles are always the same, although the methods adopted are very varied in detail.

134. It is important to point out that the magnitude of the E. M. F. induced in a conducting loop does not depend upon the total flux which may be poured into the loop, but upon the rate at which the entry and exit are made. A large total flux, entering slowly into a loop, may produce less E. M. F. in magnitude than a small total flux entering rapidly. For this, reason, the E. M. F.

generated by a dynamo increases with an increase in the speed of revolution of its armature.

135. A resultant E. M. F. is never produced in a conducting loop, by its passage through flux, unless the amount of flux entering the loop is different from that leaving it. Thus, if the conducting ring A B C, in Fig. 59, with its plane at right angles to the uniform flux, be moved at right angles to the flux, then it will have no resultant E. M. F. generated, since the flux it en-

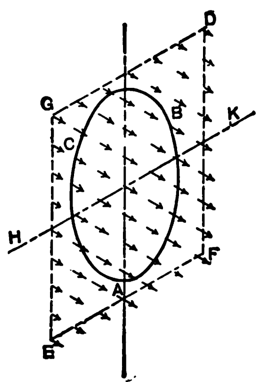

FIG. 59.
Conducting ring normal to flux, moving in plane normal to uniform flux.

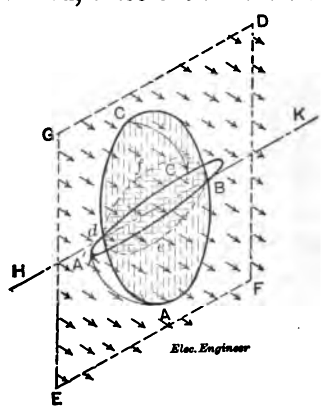

FIG. 60.
Rotation of a loop in a magnetic flux.

closes at any instant is always the same. Or, since the amount of flux cut by the advancing edge and therefore entering the loop, is equal to the amount of flux cut by the following edge and therefore leaving the loop, the equal and opposite E. M. F. generated in these two halves of the ring exactly neutralize.

136. If, however, a conducting loop be rotated in a magnetic field, a resultant E. M. F. will be generated in it. If, for example, the loop A B C, be rotated

round the axis H K, Fig. 60, it will, in different positions, have an amount of flux poured into it differing from that poured out from it. If at any instant, the rate at which flux is being emptied or introduced were continued unchanged for one second, the amount of flux (webers) leaving or entering in that time, would be the resultant E. M. F., in C. G. S. units, round the loop at that instant. Fig. 61 shows a device whereby an E. M. F. can

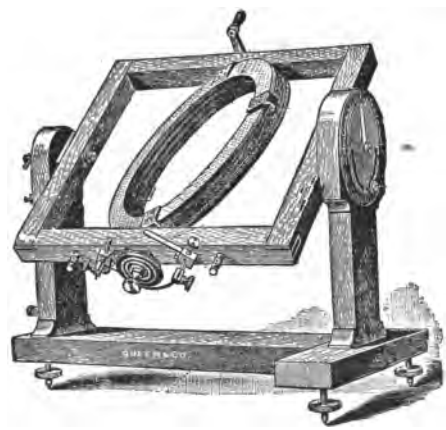

FIG. 61.
E. M. F. Produced by Rotation of Coil in Earth's Flux.

be obtained from the earth's magnetic flux, by revolving a coil of many turns, in a supporting frame.

137. When the circuit of a voltaic cell is closed through a long coil of insulated wire, an electromotive force is developed in the wire by the flux linked with the magnetic circuit established under the M. M. F. of the active conductor, and this induced E. M. F. has a direction opposed to the E. M. F. of the battery. When, however, the circuit of the battery is broken, owing to

the disappearance of the flux from the loops of the circuit, which has the same effect as the linking of flux with the loop in the opposite direction, an induced E. M. F. is produced in the wire, whose direction is the same as that of the E. M. F. of the battery. These phenomena are called the phenomena of *self-induction*. The tendency of the E. M. F. so produced is to oppose the change of current which sets it up.

138. When two conducting circuits are placed in each other's vicinity, and an electric current is established in one of them, during the time the current is increasing in strength, the flux it produces links with the neighboring circuit and develops in it an E. M. F. which is called an E. M. F. of *mutual induction*.

SYLLABUS.

When a relative motion takes place between a conducting circuit and a magnetic flux, an E. M. F. is produced in the circuit, varying in direction with the direction of the motion. The E. M. F. so developed is called induced E. M. F. and is equal, in C. G. S. units, to the total amount of flux that is, or would be, cut in one second of time. The E. M. F. of induction may, therefore, be increased by increasing the velocity of the movement or the intensity of the flux.

If the total flux linked with a circuit, including all the loops it may have, be expressed in webers, the E. M. F. in volts, induced in that circuit, at any moment, will be the rate at which the flux is changing, divided by 100,000,000.

No. 17.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
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INTERMEDIATE GRADE.

THE DYNAMO.

139. A dynamo-electric machine is a device for producing E. M. F. by successively filling and emptying loops of wire with magnetic flux. A dynamo-electric machine consists essentially of two parts; namely, (*1*) That called the field, which produces the magnetic flux; and (*2*) That called the armature, which bears the loops which are successively filled and emptied with flux.

Numerous machine designs have been produced by which these objects can be accomplished, thus giving rise to numerous classes of dynamo-electric machines.

The function of the field magnets is to provide the magnetic flux in its magnetic circuit, and the loops of wire on the armature are either carried through this flux, or the flux carried through them, so that they are successively filled and emptied. The rate at which each loop is filled and emptied determines the value of the E. M. F. generated in it, and the number of such loops

with their grouping or connection, the total amount of E. M. F. generated by the machine.

140. In the United States, continuous current dynamos have their armatures either of the drum-wound or ring-wound type. An example of the drum-wound type of armature is represented in cross-section at Fig. 39, page 93, and in perspective in Fig. 62.

Let us consider two loops, C D E F, G H J K, Fig. 63 (*a*), in a drum-wound armature, at right angles to each other, and without being connected to a commutator. These

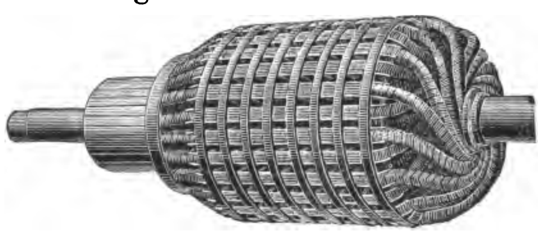

FIG. 62.
Drum Armature.

loops are supposed to be supported on the axis A B, in a bipolar flux represented as uniform by the arrows.

It will be seen from an inspection of the figure, that the two loops being at right angles, one is filled with flux, and the other is completely empty. It will be seen from Fig. 63 (*b*), that, considering the armature to be revolving at a speed of 10 revolutions per second, then in the $\frac{1}{240}$th part of a second, the loop C D E F will be advanced to the position C′ D′ E′ F′, represented by the dotted line, and the amount of flux then emptied out of it will be that included in the two narrow parallelograms $c\ c'\ f'\ f$ and $d\ d'\ e'\ e$, which are included between the projections of the sides of the loop in the two positions. If

the density of the flux be three kilogausses and the area of the two parallelograms 34 square cms., the flux emptied out in this $\frac{1}{240}$th part of a second will be $3{,}000 \times 34 = 102$ kilowebers, representing a rate of filling of $\frac{102{,}000}{\frac{1}{240}} =$ 24,480,000 webers per second = 0.2448 volts generated in the loop.

On the contrary, the horizontal loop G H J K, represented separately in Fig. 63 (*c*), will have advanced during the same $\frac{1}{240}$th of a second, to the position represented by the dotted line G′ H′ J′ K′, and will only have

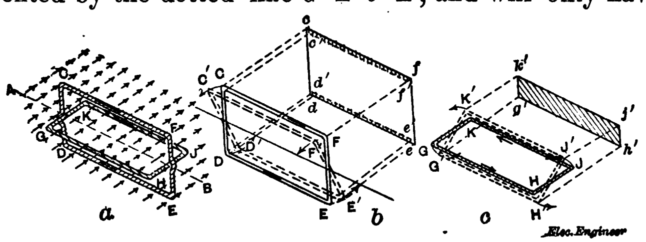

FIG. 63.

introduced into it the flux included in the parallelogram $g' \, h' \, j' \, k'$. With the same density of flux the area of this parallelogram will be 259 square cms., making a total loss of flux in the $\frac{1}{240}$th of a second = 777,000 webers, and the rate of emptying $777{,}000 \times 240$ webers per second = 186,480,000, an E. M. F. in the direction shown by the arrows of 1.8648 volts. It is easy to see that if the interval of time had been taken sufficiently small, the E. M. F. in the horizontal loop would amount to 1.885 volts, while in the vertical loop it would be zero. For loops that may lie upon the surface of the armature, between the vertical and horizontal positions, the value of the E. M. F. generated will be intermediate between zero and 1.885.

141. The rule for determining the direction of E. M. F. induced in a loop, is as follows. When a watch is held in front of an observer, the light by which he sees the dial, passes directly from the dial to his eye. If now the watch-face be regarded as a loop, then when flux is poured through it in the *same* direction as the light (*i.e.*, entering at the back and passing towards the observer), the E. M. F. around the loop will be in the *same* direction as the motion of the hands of the watch. If, on the contrary, the motion of the flux be *against* the motion of the light the direction of the E. M. F. will be *against* the direction of the hands of the watch.

Decreasing, or pouring-out flux, produces an E. M. F. in the opposite direction to increasing or pouring-in flux. Thus, if the loop C D E F, Fig. 63 (*a*), be rotated about its axis A B, in the flux indicated by the arrows, into the position represented by the dotted lines, it will be pouring flux out, equivalent to having flux poured into it from the opposite side, and the E. M. F. induced around the loop, during the passage shown, will be in the direction of the arrows. The application of this rule to the loop, shown in Fig. 63 (*c*), will show that the rotation of the loop, in the direction indicated by the arrow, will produce an E. M. F. which will be directed during the motion of the loop from G to H, and from J to K.

142. A diagram representing a ring-wound armature, commonly called a Gramme-ring armature, from the name of the French electrician, Gramme, who first employed it in practice, is shown in Fig. 64 (*a*).

The flux is supposed to enter the ring on the side B C D E F, and to leave it at the side M L K J H.

It will be observed that the flux fills the loops at the

top and bottom of the ring, while the loops on the horizontal line are empty; the intermediate loops, having intermediate quantities of flux passing through them. As before, the E. M. F. in the horizontal loops will be a maximum, since, at this position, the rate of filling is a maximum, and the loops on the vertical line have no E. M. F. in them.

143. Fig. 64 (*b*), shows the connection of the loops on the Gramme ring in a single series to form a complete circuit. When the ring is set in rotation, the

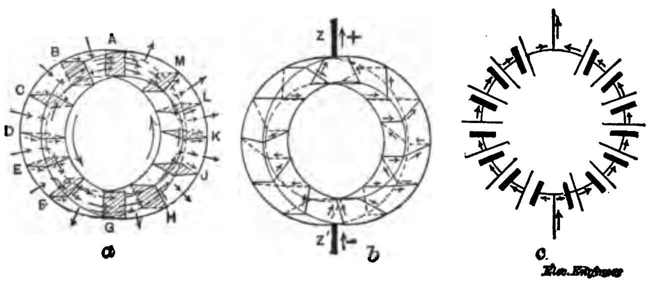

FIG. 64.

E. M. F. in the various turns unite on one side of the vertical line to produce a total E. M. F. which is equal and opposite to that produced by the loops connected in series on the other side of the vertical line, so that, provided the winding be uniform, and not dissymmetrical, no current will be produced in the ring, the two opposing E. M. F.'s balancing, for otherwise wasteful currents would probably be set up in the armature. If two brushes, z, z′, were placed at points on the vertical line, so as to maintain contact with the armature wires during its rotation as they come round, then the E. M. F.'s generated in the opposite sides of the armature would tend

to pour a continuous current through the circuit connected with the brushes. In practice, since the armature is wound with insulated wire, often laid on in several layers, it is found convenient to carry out connections at regular intervals to insulated conducting segments of a device called a *commutator*. The brushes are rested on the surface of the commutator at the proper points. The voltaic analogue of the E. M. F.'s in the armature are shown in Fig. 64 (*c*).

144. The amount of E. M. F. produced in any case may be determined by the following rule. Multiply the total flux in webers, passing through each pole into the armature, by the number of revolutions of the armature per second, and by the number of wires counted once round the surface of the armature. The quotient divided by 100,000,000 will give the volts. The total flux may be determined when the total reluctance of the magnetic circuit, or circuits and the M. M. F. of the field magnets are known.

145. The output of a dynamo machine is most conveniently given in kilowatts, and is found by multiplying the pressure in volts which the machine sustains at its terminals, by the current in amperes it maintains at full load. Thus, a railway generator producing a current of 952.4 amperes at 525 volts terminal pressure, will develop in the external circuit an activity of $952.4 \times 525 = 500{,}000$ watts, and the machine will be a 500 K. W. machine. In practice a certain relation always exists between the output of a machine, its E. M. F., and internal resistance. It is evident that if the resistance of the machine exceeds a certain value, the

current passing through that resistance at a continuous E. M. F. and output, would produce an excessive and dangerous amount of heat in the machine. Indeed, in practice, the only electrical difference existing between a 3,000 K. W. machine, say, of 500 volts, and a one K. W. machine, at the same pressure, lies in the resistance of its armature.

146. Were it practicable to operate a dynamo on short circuit, the maximum possible activity would be obtained, and would be equal to $EI = E \times \frac{E}{r} = \frac{E^2}{r}$ watts, where E, is the E. M. F. of the machine in volts, and r, its internal resistance in ohms. This theoretical maximum output may be called the *electrical capability* of the machine, and, in practice, a certain fraction of this electrical capability may be taken as the output. This fraction varies with the character and size of the machine, from 0.1 in small machines to, say, 0.02 in machines of 200 K. W.

147. The electrical capability of a machine is not altered by the size of the wire employed in the winding, provided the volume of the winding space on the armature be maintained constant, and that the proportion of space allotted to insulation remains constant. Thus, if the diameter of the wire employed be halved, there will be room for four times as many wires, and the total resistance of the armature will be increased 16 times, since the length has been quadrupled, but the cross-section of each turn reduced to one-fourth. The ratio of E^2 to r, will be $\frac{16}{16}$; *i.e.*, will remain the same. This is equivalent to the statement, that, provided the

insulation space of the armature remains constant, the output of the machine remains the same at any voltage, so that if the same machine be wound for 30 or 60 or 100 volts, its output will remain unchanged.

Syllabus.

When the flux is being poured into a loop in the same direction as the light passing from a watch face towards the observer, the direction of the induced E. M. F. is the same as the motion of the hands of a watch.

The electrical capability of a machine is equal to square of its E. M. F. in volts, divided by its resistance in ohms. The electrical capability bears a ratio to the output varying according to the type and size of the machine. This ratio is within wide limits independent of the E. M. F. for which the machine is wound.

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Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

THE DYNAMO.

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148. By the electrical efficiency of a dynamo is meant the ratio between the electrical activity in the external circuit of the machine, and the total electrical activity it produces both in its internal and external circuits. Thus, if a dynamo develops an activity of 100 kilowatts in its external circuit (say, 1,000 amperes at 100 volts, as measured at its terminals), and expends, electrically, four kilowatts in its armature and field magnets, *i.e.*, internally, then the total electrical activity in the circuit will be 104 K. W., and the electrical efficiency of the machine will be expressed by

$$\frac{\text{External Activity}}{\text{Internal Activity} + \text{External Activity}} = \frac{100}{104} = 0.9615.$$

The commercial efficiency of the machine differs from this, and is the ratio existing between the output of the machine and its intake. Thus, if the same machine expended, besides the four KW. in its field and armature, say, five KW. in mechanical friction and other losses,

then the total activity expended in the machine will be nine KW., and its commercial efficiency will be

$$\frac{\text{External Activity or Output}}{\text{Intake}} = \frac{100}{109} = 0.9174.$$

149. **In any generator the following losses prevent the output from being equal to the intake; namely,**

(*1.*) Mechanical losses, including friction of all kinds.

(*2.*) Electrical losses. These are of two kinds; that in the conducting circuit on the armature due to the passage of an outgoing current through the resistance of the armature, and that due to small local or eddy currents in the substance of the wire on the armature, or in the iron of the armature core and pole-pieces.

(*3.*) Magnetic losses, or those due to the reversal of the magnetism in the iron.

150. The mechanical losses may be classed as follows, viz., air friction, brush friction and journal friction.

If the armature resistance of a 100 KW. dynamo be 0.005 ohm, and the current it delivers 800 amperes, the activity expended in heating the armature wire will be $i^2 r = 800 \times 800 \times 0.005 = 3{,}200$ watts; *i.e.*, 3,200 joules per second.

The loss in the armature winding of a generator of one KW. capacity is often 12 per cent. of the output, while in the armature winding of a 200 KW. generator it is usually about two per cent. of the output.

Similarly, if the field magnets require a current of eight amperes to excite them and are supplied direct from the brushes, the energy expended in heating their

circuit will be $E\ I = 125 \times 8 = 1{,}000$ watts. This amount will vary considerably with the type and size of machine, say, from 10 per cent. of the output in a 2 KW. generator to 1.5 per cent. of the output in a 200 KW. generator. These losses constitute the electrical losses in the circuits of the machine.

The rapid reversals of magnetism to which the iron in the armature and in the pole-pieces is subjected, during the operation of the machine, set up E. M. F.'s in these masses which in their turn produce local, deleterious currents in the iron, called *eddy currents.* Although the E. M. F. producing these currents may be only a small fraction of a volt, yet the resistance of the mass of metal in which they are set up, being also very small, the actual currents produced may be seriously large; hence it is necessary to check the establishment of these wasteful currents by limiting the mass of metal in which they can exist as a single circuit. This is accomplished, in practice, by laminating the iron in a direction parallel to the direction of the magnetic flux. It is not necessary elaborately to insulate the separate laminæ or sheets of iron so employed, since the film of oxide always present on their surfaces is sufficient to prevent the feeble E. M. F.'s from crossing them. Where, however, great mechanical pressure is brought to bear upon such surfaces during construction, they are generally insulated, either by dipping them in shellac varnish, or by interposing sheets of tissue paper.

151. Similar eddy currents are also set up in the substance of the copper wire on the armature; and, when such conductors are of large cross-section, it is necessary to subdivide that cross-section by transposing

and stranding the conductors; *i.e.*, by dividing them into a number of separate conductors. If, however, the wire be wound in grooves on the armature core, as in the case of toothed armatures, or armatures having iron projections, lamination of the conductors is rendered unnecessary, since the copper is practically insulated from the flux which links with it, and which passes almost entirely through the iron teeth. All electrical losses of the character of eddy currents belong to the $I^2 R$ type, and, since I, increases with the E. M. F., which in its turn increases with the speed, such losses increase as the square of the speed of rotation. If, therefore, the losses due to eddy currents in a given machine are 300 watts, at its normal speed, they would amount to 1,200 watts, if the speed were doubled.

152. The magnetic losses, which occur in the iron of the armature core, are due to what is called *magnetic hysteresis* (his-ter-ee′-sis). The word hysteresis, derived from the Greek, means *a lagging behind*, thus characterizing the lagging of the magnetization in the iron, or other magnetic metal, behind the magnetizing flux. That is to say, when a magnetizing flux is brought to bear upon a piece of iron, the molecules of the iron become aligned, as already explained. On the withdrawal of the magnetizing flux, the bar does not instantly lose its magnetism; *i.e.*, its alignment, but tends to retain the same for a short time, and does not reach a condition of demagnetization until the flux has not only disappeared but has actually been reversed. In other words, the magnetic flux in the iron lags behind the magnetizing flux.

153. When a magnetic flux is produced in air around a conductor, energy is absorbed into the ether and air from the circuit; but, on the cessation of the current, all this energy is returned to the circuit electrically. If, however, iron be magnetized by the current, energy will be absorbed from the circuit, both by the ether and by the iron, with this difference, that while the energy in the ether will be restored to the circuit as electrical energy, on the withdrawal of the magnetizing flux, that in the iron will be only partially restored to the circuit, as electrical energy, the balance being expended in the iron as heat. Since the same amount of heat is produced at each cycle, at every reversal, if the iron be carried through 50 cycles (50 double reversals of magnetism per second), there will be 50 times as much energy expended in a cubic centimetre, or cubic inch, as if only a single cycle were made per second. As the limiting flux density, through which the iron is carried in each cycle, is increased, the hysteretic loss increases in greater ratio, and a doubled range of flux density is accompanied by approximately a trebled loss of energy in hysteresis. Thus, if an iron armature be revolved in a bipolar magnetic field 20 times a second, every cubic inch of iron will be magnetized from, say, a flux density of 5,000 gausses in one direction, to 5,000 gausses in the opposite direction, in 20 complete cycles or double reversals per second, and every cubic inch of such iron will have expended in it 0.0543 joules per second. If now the field magnets be excited by an increased current, so as to bring the flux density in the armature up to 10,000 gausses, the range of reversal will be doubled, and the hysteretic loss in every cubic inch will be practically

trebled; *i.e.*, increased to 0.165 joule per second, or an activity of loss of 0.165 watt.

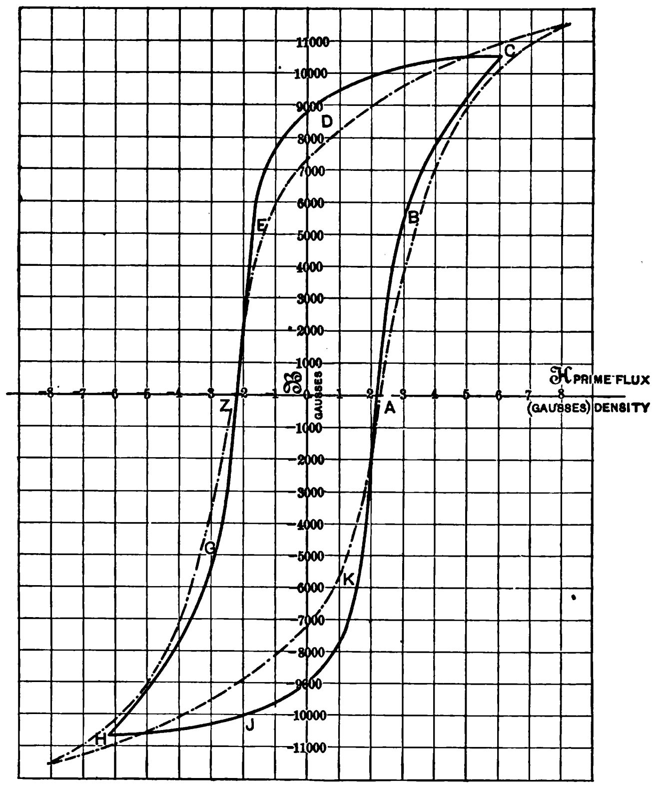

FIG. 65.

Hysteretic Diagrams of Charcoal Iron Rings and of Hard Cast Steel.

Charcoal Iron:—Full line to indicated scale. From observations of Kennelly. $\mathcal{H} \pm 6$, $\mathcal{B} \pm 10{,}600$.

Hard Cast Steel:—Broken line, to 10 times indicated scale. From observations of Steinmetz. $\mathcal{H} \pm 82$, $\mathcal{B} \pm 11{,}500$.

154. Fig. 65 represents what is called a hysteretic diagram or cycle, and shows how the flux density in iron varies with the cyclic variation of the magnetizing flux. Thus the prime intensity or magnetizing flux which will bring this sample of iron to an intensity of $\mathcal{B} = 10,600$ gausses is 6.1 gausses; carrying back the magnetizing force, *i. e.*, reversing it from $\mathcal{H}$ back to zero, the intensity in the iron does not return along the same path A B C, it took during ascension, but descends along the more slowly returning curve C D E, and, when the magnetizing flux reaches zero; *i.e.*, when the magnetizing flux is completely withdrawn, there is still a residual magnetic flux of $\mathcal{B} = 8,900$ gausses in the iron. In fact, the magnetic flux has to be carried back to z or — 2.2 gausses, in order to destroy the magnetic flux in the iron, *i. e.*, to reduce it to zero. This negative magnetizing flux 0 z, in gausses, is the measure of the hardness of the sample of iron. Very soft iron will take a small negative 0 z, to destroy its flux, while hard steel requires a powerful 0 z. In fact, 0 z, is the measure of the coercive forces or retentivity in the iron. Continuing the magnetizing flux to — 6.1 gausses, the flux density in the iron descends to — 10,600 gausses, or becomes equal in intensity to its value at C, but in the opposite direction, and the cycle is completed along the line H J K L C, by reversing the magnetizing flux from negative to positive. The area of this loop is a measure of the loss of energy in the iron. The broken line cycle represents a corresponding diagram for hard steel, drawn to one-tenth scale in magnetizing flux. It will be seen for the same range of flux density in steel that the area of the loop inclosed would be about ten times greater, if drawn to the same scale.

If these various losses are summed and deducted from the intake of the generator, the balance will be the output of the machine, and the ratio of this output to the intake will give the commercial efficiency.

Syllabus.

The electrical efficiency of a generator is the ratio of the external activity to the total electrical activity.

The commercial efficiency is the ratio of the output or external activity, to the intake.

The output of the machine is lower than the intake on account of losses arising from mechanical friction, electrical friction, and magnetic friction.

Hysteresis is the lagging of the magnetization in a magnetic metal behind the magnetizing flux.

Eddy current losses in a dynamo-electric machine increase with the square of the speed of rotation.

Hysteretic loss increases directly with the speed of rotation.

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—BY—

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INTERMEDIATE GRADE.

THE DYNAMO.

155. In practice it is impossible to obtain from a generator the maximum output which it is capable of producing, since at a certain critical output, varying with the type and character of the machine, a limitation is reached due to one or more of three considerations; namely,

(1.) A limitation due to excessive drop in the armature, an insufficient E. M. F. remaining at the termminals.

(2.) A limitation due to overheating of the machine.

(3.) A limitation due to dangerous sparking at the commutator.

156. A generator is capable of producing a certain maximum E. M. F. The drop of pressure due to $I\ R$, increases with the load, principally owing to the increase in I, the current strength delivered, and partly because, as the temperature of the machine increases, the value of R, increases by about $\frac{1}{4}$ per cent. per degree Fahrenheit. If the drop becomes excessive,

the E. M. F. remaining at the terminals may be insufficient to deliver the pressure required. Thus, if a generator, connected to an incandescent light circuit, has a maximum E. M. F. of 125 volts, and the drop in the machine be eight volts, the pressure at maximum E. M. F. will be 117 volts, which will be insufficient to bring the lamps up to candle-power if they be made for 120 volts pressure. The output will, therefore, have to be reduced in order to bring the lamps up to candle-power. When, however, a dynamo has been properly installed with a view to the work it has to perform, its limitation to load is not usually want of pressure. Such a limitation is more readily encountered in small generators than in large ones.

157. In the practical operation of generators, the principal limitation of output is that due to excessive heating. Although heat is produced in both the field and armature, through the influences of the losses of energy taking place in the machine, yet the principal elevation of temperature is usually found to be in the armature.

Were it possible to construct an armature of a dynamo of iron and copper only, that is, without any solid insulating material, the only objection that would exist to operating the generator at such an output as would produce a high temperature, say 300° C. in the armature, would be the commercial value of the energy expended in the resistance of the machine at this temperature. Since, however, insulating material, of a character readily damaged by excessive heating, has to be employed, the critical temperature beyond which it is undesirable to operate a generator is far lower, say 100° C. This maximum temperature of 100° C. would represent a

temperature elevation of 75° C. above the normal temperature of the air, assumed at 25° C. But the output, which would permit of such an elevation of temperature, would not be possible in cases where the surrounding temperature happened to be 35° C., and would prevent any allowance for accidental overload. Taking both these liabilities into account, it is found desirable in practice to limit the temperature elevation of a generator to 50° C. above surrounding objects, representing in the case of a normal temperature of 35° C., a temperature attained of 85° C., and allowing even then a margin for accidental overload without endangering the insulation of the machine. Conservative practice is, however, reducing this heat elevation to 40° C.

158. A machine with a very low temperature elevation is a machine with a large reserve of output, unless that reserve be annulled by a tendency to sparking or by excessive drop of pressure. When a generator is started at full load, its rate of increase of temperature is a maximum and diminishes as time goes on, owing to the fact that it tends to attain its ultimate condition, in which the loss of heat from the armature is exactly equal to the rate of generation of heat within it.

The heat generated in the armature is dissipated from its surface by conduction, radiation, and convection. The velocity with which these influences enable the heat to be carried away, varies with the dimensions, speed, and type of machine, but it is usual to allow a certain amount of surface to the armature for a given known amount of energy expended within it; for ordinary drum-wound armatures this allowance is usually, 0.15 watt per sq. cm., (approximately one watt per sq. inch.)

In specially ventilated, hollow armatures this allowance can sometimes be increased to 0.45 watt per square centimetre; (approximately three watts per square inch.)

159. Generators are usually guaranteed not to elevate their temperatures at any part more than a certain limit above the surrounding air, during a prolonged run at full load. The instrument ordinarily employed to measure the elevation of temperature is a naked thermometer placed on some part of the machine and covered by some thermal non-conducting material, such as cotton-waste. In order to apply the thermometer to the armature, the machine has to be stopped and a certain time has to elapse before the thermometer applied to the surface of the armature can attain its maximum reading, since the the interior of the armature will have a higher temperature than that on the surface and time is required for the maximum temperature of the surface to be reached.

160. The remaining limitation of output, namely, that due to dangerous sparking at the brushes, is usually reached in well-designed machines at outputs greater than those of temperature elevation. The sparking, which always occurs at continuous-current dynamo brushes in a greater or less degree, is due to the effect of inductance in the coil which the brush is breaking contact with at the commutator, owing to the E. M. F.. which is developed in that coil by the sudden reversal of its current.

Thus, in Fig. 66, which represents diagramatically a portion of a Gramme-ring armature, the brush H, is resting on the commutator bar *b*, connected with the coil B,

the directions of the current in the winding being indicated by the small arrows, and the direction of motion of the armature indicated by the large arrow. Since the effect produced is one of relative motion, the rotation of the armature, in the direction of the arrow with the brush at rest, will be equivalent to the rotation of the brush over the commutator in the opposite direction to the arrow with the armature remaining at rest. In this way we may suppose the brush carried from H to *h*. In so

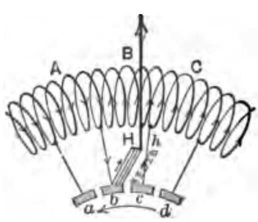

Fig. 66.
Commutation of segments on the Gramme-ring armature.

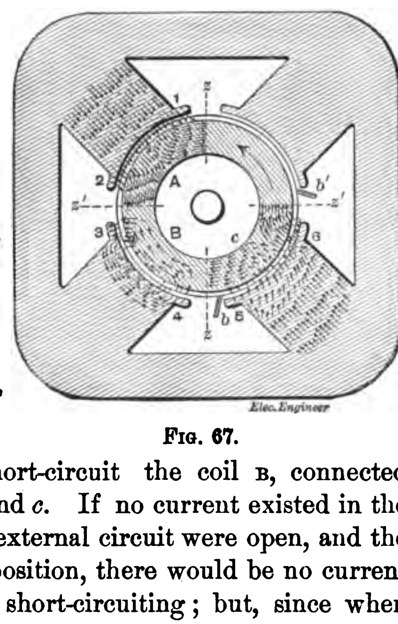

Fig. 67.

doing it will first short-circuit the coil B, connected with the segments *b* and *c*. If no current existed in the armature, *i. e.*, if the external circuit were open, and the brush is in the right position, there would be no current in the coil B, during short-circuiting; but, since when the load current is flowing through the armature all the coils on the left hand side of the brush have currents flowing through them downwards, as indicated by the arrows, and all on the right hand side upwards, as similarly

indicated, a reversal of the current in each coil must take place during the period of short-circuiting. If the reversal has not completely taken place during this period, there will be a tendency for a spark to follow the brush from the segment *b*, when the brush is transferred from *b* to *c*, owing to the E. M. F. in the coil, set up by the sudden reversal of its current. When, therefore, the load current is strong in B, it is necessary to employ a counter E. M. F. in B, for the purpose of reversing its current during the period of short-circuiting. This is accomplished by giving the brushes a *lead*, or a movement forward in the direction in which the armature is rotating, in order to bring the coil under reversal into flux from the field magnets, the direction of which is calculated to reverse the load current in B, by its movement during the period of short-circuit.

161. As the current load increases, to prevent sparking, this lead of the brushes has to be increased in order to bring the coil into stronger flux. As soon, however, as a certain current strength is reached, no increase in the lead will have any effect in diminishing the sparking. The reason for this will be seen from an inspection of Fig. 67, which diagrammatically represents a four-pole generator in which *z z*, and *z′ z′*, respectively, represent th. *diameters of commutation*, or the position at which the brushes should be applied to the armature, in order to carry off the currents. When current is taken from the armature, the brushes require to be shifted into positions such as *b* and *b′*; *i.e.*, given a lead in order to prevent sparking. At the quadrant A, the flux is represented as passing from pole to armature under normal circumstances with no M. M. F. in the armature and full

M. M. F. in the field. At quadrant B, the flux is indicated as it may be produced under M. M. F., from the armature with a strong load current through its windings, and no M. M. F. in the field, and represents a condition of armature excitation taking place under the pole A, when the load current flows through the armature.

At quadrant *c*, these two effects are superposed, and a distortion results in the distribution of field flux, as shown, whereby the intensity in the air and armature are increased at the edge of the pole 6, and decreased

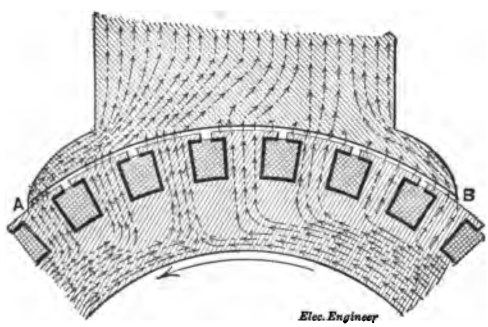

FIG. 68.
Section of one Quadrant of a 4-pole Generator with Tooth-cored Armature.

at the edge 5. This distortion due to armature reaction weakens the controlling flux at the position where commutation is taking place, and towards which the brush has been moved. It is, therefore, necessary to still further advance the brush in order to bring the commutated coils into a stronger flux. A load current will finally be reached at which it is impossible to obtain the controlling flux near the position of commutation, and, at such a current strength, no amount of lead in the brushes avails for checking sparking. This current is beyond the sparking limitation of the machine.

162. Toothed armatures, however, such as shown in Fig. 68, if properly designed, can be made to carry a stronger current without sparking than smooth-core armatures; for the tendency to crowd the flux at the leading corner of the pole pieces, and denude it at the trailing corner, is opposed by the increasing reluctance which the iron teeth can be caused to exert towards such increase of intensity, if they are brought sufficiently near to such reluctance under the ordinary conditions of load.

Syllabus.

The limitations to the output of a dynamo are of three types; namely,

(1.) Those due to fall of pressure in the machine.

(2.) Those due to excessive heating in the machine.

(3.) Those due to dangerous sparking at the brushes.

Limitations arising from drop are reached when the maximum pressure, available at the armature terminals, falls below that required by the circuit.

The limitations due to heating of the machine are imposed for insuring the safety of the insulation of the conductor on the machine.

The limitations due to sparking are imposed for insuring the proper operation and durability of the commutator.

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INTERMEDIATE GRADE.

THE REGULATION OF THE DYNAMO.

163. In the practical operation of dynamos, whether their circuits are intended for constant current or constant potential (see sections 62 to 72) a necessity exists for maintaining such constancy when the number of electro-receptive devices placed in such circuits is varied. Such regulation of dynamos is accomplished either automatically or by hand.

We have seen that the E. M. F. of a generator depends on its speed, on the number of conductors on its armature, counted once around, and on the flux passing through the armature. The speed and the number of conductors remaining the same, the variation of E. M. F. is obtained either by altering the flux through the armature, by means of a change in the M. M. F. in the coils of the field magnets, or by altering the position of the brushes on the commutator, so as to deliver into the external circuit a greater or lesser proportion of the E. M. F. generated in the armature.

164. In constant-current machines, which are almost exclusively employed for series-arc circuits, the excitation, that is, the M. M. F. in the magnetic circuit, is usually maintained constant, and the variation of E. M. F. is obtained by changing the diameter of commutation, through the shifting of the brushes. Constant-current machines may be automatically controlled to supply any number of lights, say, between one and 60, representing a corresponding variation of E. M. F. of from 50 to 3,000 volts.

In constant-potential generators, which are almost exclusively employed for continuous-incandescent and

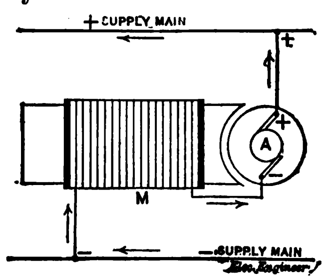

FIG. 69.
Series-wound generator.

power circuits, the brushes are either not moved at all, or are only slightly shifted to maintain sparkless commutation, and the necessary variation of E. M. F. required, is either obtained by altering the current strength passing through the field magnets, by means of hand regulation, or by providing an additional field-winding in the circuit of the armature; that is, by the compound-winding of the machine.

165. Generators may have the circuits of the armature and field magnets connected either in series or in parallel. In the former case, represented in Fig.

69, the generator is series-wound. In the latter case, shown in Fig. 70, the generator is shunt-wound. Here a rheostat r, is inserted to control the M. M. F. of the field-magnet. A series-wound machine tends to increase its E. M. F., as its load increases, since then the M. M. F. of its magnets increases, thus forcing more flux through the armature and raising its E. M. F. Shunt-wound machines, on the contrary, tend to diminish their E. M. F. as their load increases, partly owing to drop of pressure due to IR, in the resistance of the armature, and partly

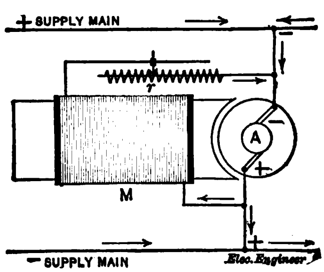

FIG. 70.
Shunt-wound generator.

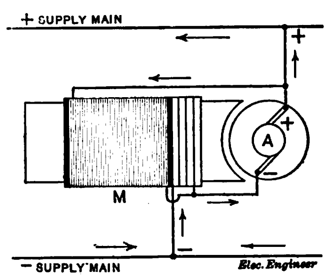

FIG. 71.
Compound-wound generator.

owing to the reduction of flux through their armatures, as a consequence of the reduced M. M. F. so effected.

By suitably winding a machine, in accordance with both of the preceding types, the compound-wound generator, represented diagrammatically in Fig. 71, can be produced, which will maintain its pressure at the terminals practically constant from no load to full load. The fall in pressure on an increase of load, which would take place in it considered as a shunt-wound machine, being offset by the rise in pressure, which takes place in it considered as a series-wound machine.

166. The following is a classification of the three principal types of continuous-current generators, together with an enumeration of the purposes for which they are generally employed:

Generators	Series-wound......	Series-arc lighting. Series-incandescent lighting (continuous).
	Shunt-wound......	Central station incandescent-parallel systems. Some motor circuits.
	Compound-wound..	Isolated incandescent-parallel systems. Street railroad systems. Motor systems.

167. The adjustment required in order to maintain, automatically, a constant potential at the terminals of a generator is effected by ascertaining the amount of drop in pressure, which would be produced if the M. M. F. of the machine were maintained constant, and then determining how great an increase of M. M. F. is necessary in order to restore the drop of E. M. F. This can be done by determining the reluctance of the various branches of the magnetic circuit in the dynamo, and by the corresponding Ohm's law for magnetic circuits, $\Phi = \frac{\mathcal{F}}{\mathcal{R}}$, calculating the increase in $\mathcal{F}$, necessary to make the required addition in Φ, and also owing to the necessarily increased reluctance $\mathcal{R}$.

168. A very close regulation in pressure is required for the efficient operation of incandescent lamps. For example, if a system of incandescent lamps in a building, wired for 115 volts and 0.4374 ampere, each (50 watts), be steadily operated at 116 volts, *i.e.*, at one

volt above pressure, the illuminating power of the lamps will be increased at the outset to about 17 candles, and the average lifetime will be diminished about 17 per cent.; while if the pressure be permanently raised two volts, or to 117 volts, the initial illuminating power will be raised to nearly 18 candles, and the lifetime probably reduced 33 per cent.

169. When several shunt-wound generators are connected in parallel, as in a central station for supplying incandescent lighting, it is essential to maintain the E. M. F. of the generators within close limits for another reason. If two shunt-wound generators be running in parallel with a terminal pressure of 120 volts, with a drop in the armature of, say, 2.5 volts, then a diminution of speed amounting to two per cent. in the engine driving one of them, will reduce the E. M. F. of that machine to 120 volts. Under these circumstances no current will flow through the retarded generator, and the lighting load will be entirely thrown off its engine. The tendency, therefore, will be for the engine to accelerate and recover its share of the load; but, should this not be the case, and should the engine continue to slacken in speed, say, one per cent. further, the E. M. F. in its generator will fall below the pressure at the terminals of its neighbor, and a current will pass through its armature in the reverse direction. The result will be that the generator becomes a motor, and power will be exerted towards driving its engine faster at the expense of load on the remaining generator. It is evident, therefore, that three per cent. of variation in speed, if unchecked, would be sufficient, under these circumstances, to convert an active generator into a motor.

170. Fig. 72 shows, diagrammatically, the connections for two shunt-wound generators arranged for operation in parallel. In starting, one machine only, say A, is operated, its own engine being brought up to speed, and the resistance r, entirely cut out, leaving the shunt winding directly connected to the brushes. This enables sufficient current to be produced in the armature, under the influence of the residual magnetic flux in the circuit, to generate increasing M. M. F. in the magnetic circuit, and from this, an increasing E. M. F. of the armature.

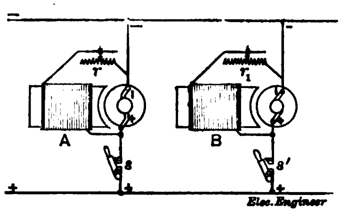

FIG. 72.
Connections of two hand regulated shunt-wound generators in parallel.

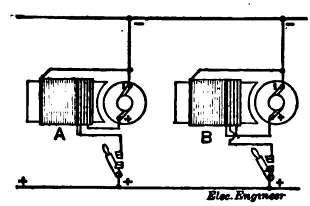

FIG. 73.
Connections of two compound wound, self-regulating, generators in parallel.

This mutual action and reaction, between the electric and magnetic circuits, produces an accumulated E. M. F., or, as it is commonly called, a "*building-up*" of E. M. F. As soon as the machine attains its full pressure, as indicated by a voltmeter connected with the brushes, sufficient resistance in the rheostat r, is introduced into the circuit to maintain that pressure, and then the switch s, is closed, thus connecting the E. M. F. of the machine with the *bus bars* + and —. As soon as the load becomes too great for a single generator, the second machine B, is thrown into action, by running its engine up to speed, short-circuiting its rheostat, building-up its

E. M. F., adjusting that E. M. F. by the rheostat to the pressure on the mains, and then, at that pressure, closing the switch s^1. A slight increase in the E. M. F. of the machine B, will enable it to then share the load with A, and the final adjustment is usually made by the observation of ammeters in their respective circuits. When the load diminishes sufficiently to permit a single generator, say A, to sustain it, the reverse steps are followed; namely B, has its pressure lowered by means of the rheostat r_1, until little or no current passes from this machine to the bus bars. The switch s^1, is then opened and the engine driving B, is then stopped. The brushes of the slackening machine are never lifted, nor the field circuit broken, until the machine is at rest, lest the powerful E. M. F. of self-induction, set up by suddenly breaking the field circuit, should damage the insulation of field or armature.

171. Fig. 73 shows, diagrammatically, the action of two compound-wound, self-regulating generators, arranged for connection to the bus bars in parallel. Here the same steps are followed as before for connecting the machines successively to the circuit, except that little or no adjustment is necessary in the shunt circuit, the pressure being automatically maintained by the coarse and fine windings of the field; the machine will tend to divide the load if the engines are well governed and uniformly driven.

172. The danger of employing shunt-wound machines for incandescent lighting, is that, if a short-circuit takes place between the mains, the tendency will be for the field magnets to become thereby weakened,

owing to the heavy drop at the machine terminals and the reduction of M. M. F. by armature reaction. This may often act as a safeguard to the armature against a dangerously strong current. If, however, the machine be compound-wound, as in Fig. 71, a short-circuit will not tend to demagnetize the field magnets, and the current will increase until either the fuse in the circuit is melted, until the engines are stopped, or until a breakdown occurs in the circuit.

SYLLABUS.

In practice, generators are usually required either to maintain a constant current under all variations of E. M. F., or a constant E. M. F. under all variations of current.

The automatic regulation of pressure, in a constant-current machine, is almost invariably effected by automatically shifting the position of its brushes on the commutator.

The automatic regulation of pressure in a constant-potential machine is almost invariably effected by compound-winding.

In constant-potential machines, supplying incandescent lamps, close regulation is desirable in order to operate the lamps to their best advantage.

No. 21.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ELECTRODYNAMICS.

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173. *Electrodynamics* is that branch of electricity which treats of the mutual attractions between neighboring electrical conductors traversed by currents, or between such electrical conductors and magnets. *Magnetodynamics*, sometimes included under the head of electrodynamics, treats of similar attractions and repulsions between neighboring magnets. The phenomena of electrodynamics and of magnetodynamics are essentially the same.

For example, in a continuous current electromagnetic motor, the turns of conductor carrying currents and supported upon the armature, are apparently attracted by the poles of the field magnets, and, in obedience to such forces, the armature is set in rotation. So too, when a small compass needle is placed near a conductor carrying a current, the needle tends to set itself at right angles to the conductor in obedience to the laws of electrodyna-

For example, Fig. 76 represents a horizontal loop of conductor A B C D, carrying a current of, say, 20 amperes, and situated upon the surface of a motor armature, in a uniform external flux supplied by bipolar field-magnets. Under the electromagnetic force acting upon this loop it rotates upon its axis until it occupies a vertical position *a b c d*, in which it contains say 10 megawebers of flux. Then the work done by the armature during this quarter revolution, owing to the electrodynamic action of this turn, will be $\frac{20 \times 10{,}000{,}000}{10} = 20{,}000{,}000$ ergs $= 2$ joules $=$ 1.476 lbs. lifted one foot at Washington. This amount

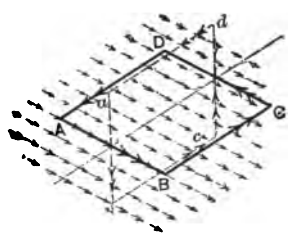

Fig. 76.

Diagram of rectangle of active conductor A B C D, situated in a uniform magnetic flux.

of energy has been absorbed from the source of electric current supplied to the armature, and has been developed against the E. M. F. established in the turn of wire by its motion through the magnetic flux. If the circuit instead of forming a single loop, consists of a number of loops, as, for example, a coil, then the amount of work done by the electromagnetic forces upon such an assemblage of loops is the sum of $\frac{i\,\Phi}{10}$ for each loop separately, and, if the increase of flux be equal for all the loops, the total

amount of work will be $\frac{i\,\Phi}{10}$, multiplied by the number of loops. If there were 600 loops of wire on the armature of the motor previously considered, each turn would exert two joules of work in a quarter revolution, and the total work expended would be 1,200 joules per quarter revolution, or 4,800 joules per revolution. If the motor made 720 revolutions per minute, or 12 revolutions per second, it would develop $4800 \times 12 = 57{,}600$ joules per second, or 57.6 KW.

The work done by an electrodynamic force is invariably obtained from the circuit or circuits in which the force is produced. Thus, when a loop moves in a magnetic flux, its motion induces an E. M. F. in the loop, which is opposed to the direction of the current in the loop, and if this E. M. F. be denoted by e, volts the work is absorbed by the loop from the source of current at the rate of $e\,i$, watts.

177. The tendency of electrodynamic forces is to bring the external or prime flux into parallelism with the flux produced by the current in the active loop. The loop endeavors to embrace as much flux as it can in the same direction as that produced by its own M. M. F. If the external or prime flux passes through the loop in the opposite direction to that produced by its own M. M. F., the loop will tend to diminish or expel the external flux, and the work done will be $\frac{i\,\Phi}{10}$ ergs, as before, Φ, being now reckoned as flux expelled and not as flux linked. Thus, in a motor armature when a given loop reaches the vertical position, it will contain a maximum amount of flux from the field magnet circuit, and, no

increase in the current carried by the loop, will produce a further rotary force; but, if by the action of the commutator, the current in the loop is reversed at the moment when it reaches the vertical position, the flux will now pass through the loop in the reverse direction to that produced by its own M. M. F., and a new electrodynamic force is exerted upon the loop until it is again filled with flux in the direction parallel to that from its own M. M. F.

178. When the loop on the motor armature has reached a vertical position in which it contains a maximum flux, and therefore exerts no force, it would not be carried past this point, which would constitute a dead point were it not for the momentum of the armature. By winding a large number of turns on the armature at equal angular distances apart, the *torque* of the armature, i.e., its rotary effort as measured by the tangential pull referred to unit radius, is rendered uniform, and momentum is no longer depended upon for its passage past its dead point.

179. We have seen that the work done by electrodynamic forces on a loop, is expressed by $\frac{i\,\Phi}{10}$ ergs, where Φ, is the flux admission expressed in webers. If, therefore, the mechanical system of the loop is such, that the only possible motion is a continued rotary motion about the axis, as in a motor armature, then for any given small angular rotation, the work done will obviously be great when the flux admission in that small rotation is great, and will be small when the flux admission is small; that is to say, the force exerted through that angular displacement, will depend upon the rate of flux admission. The torque, or tangential force at unit radius,

exerted by the loop about the axis of rotation, is equal to the current strength in amperes, divided by 20 π, and multiplied by the flux admission per unit angular displacement.

180. The electrodynamic forces here described are not confined to the mutual interactions of independent fluxes, but are produced by the action of a single electric circuit. If a current be sent through the loop of wire as shown at A in Fig. 77, the loop tends to spread outwards, as shown by the dotted arrows, so as to em-

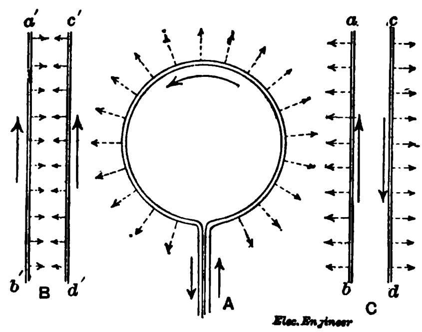

Fig. 77.

Diagrams indicating the direction of electromagnetic forces in a loop, and between parallel wires due to the flux linked with the circuit.

brace more of its own flux, and, if the circuit be composed of several loops, these will tend to move together, and always extend outwards so as to embrace as much of each other's flux, and also as much of their own flux as possible. In other words, the entire circuit tends to move so as to contain as much flux as possible. If, therefore, a free spiral or helix be traversed by a current it will tend to shorten or contract.

Similarly, two parallel active conductors, as at C, Fig.

77, carrying currents in opposite directions, are urged apart by electrodynamic force, while if, as at B, the currents flow in the same direction, the wires are urged together. In the former case the loop formed by two wires *a b* and *c d*, widens so as to embrace more flux. In the latter case the loops formed by the circuits of *a′ b′* and *c′ d′*, have the flux they embrace mutually increased by the approach of the two wires.

SYLLABUS.

Electrodynamic force exerted upon an active conductor situated in a magnetic flux, depends on the length of the conductor exposed across the flux, on the intensity of the flux, and on the strength of the current in the conductor.

The work done by electrodynamic forces in the motion of active conductors is supplied by the electric source whose E. M. F. sends the current through the conductor, and is expended by the source in work done by the current against the E. M. F. induced in the conductor during its motion through the external flux.

The work done by an active loop in any motion in consequence of electrodynamic forces is $\frac{i\,\Phi}{100{,}000{,}000}$ joules, where i, is the strength of the current in amperes, and Φ, is the flux admission in webers. If Φ, be opposed in direction to the flux from the M. M. F. of the wire, flux expulsion is equivalent to admission in its own direction.

An electric motor is a machine for the development of uniform rotary motion by electrodynamic forces.

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Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

THE ELECTRIC MOTOR.

(CONTINUOUS CURRENT TYPE.)

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181. A dynamo-electric machine may be operated either as a dynamo or as a motor; that is to say, any generator can be operated as a motor, and any motor operated as a generator, provided proper arrangements are secured for the excitation of the field magnets. The reason for this reversibility of the dynamo and motor is that electromotive and electrodynamic forces coexist in each. In the dynamo, the E. M. F. is produced by the rotation of the loops on its armature through the flux from the field magnets, but so soon as that E. M. F. is permitted to send a current through an external circuit, electrodynamic forces are set up by the current in the armature under the mutual interaction of the field and armature fluxes, and power has to be applied to the dynamo to drive it. The pressure at the terminals of the machine will be less than the E. M. F. within the machine, by an amount equal to the drop in the machine, or $i\,r$, where r is the resistance of the machine, and the electro-

dynamic force is opposed to the rotation of the machine, and may be called the counter-dynamic force.

182. On the other hand, when a current is applied to a motor, the current causes the loops on the armature to revolve through the flux from the field magnets. The loops being filled with and emptied of flux, during this revolution, generate an E. M. F. opposed to the direction of the current and, called a *counter E. M. F.*, usually abbreviated C. E. M. F. The pressure at the terminals of the motor E, volts, will be greater than the C. E. M. F., e volts, by the amount equal to the drop in the machine or $i\ r$, volts.

The distinctive feature of difference between the generator and the motor, is that in the generator the current is in the direction of the E. M. F., while, in the motor it is opposed to the E. M. F. of the machine. In one case the *output* of the machine is $E\,i$ watts, and in the other case the *intake* is $E\,i$ watts.

183. When a motor is running, as in the case of a generator, (see Sec. 144,) its C. E. M. F. is the product of the number of revolutions per second, the number of wires on the surface of the armature, counted once around, and the total flux in webers passing through each pole into the armature, and divided by 100,000,000. Thus, if the 25 KW. bipolar motor represented in Fig. 78, makes 900 revolutions per minute, or 15 revolutions per second, and if there are 200 wires lying on the surface of the armature, counted once around, while four megawebers pass through each pole into, or out of, the armature, the C. E. M. F. of the motor will be,

$$\frac{4{,}000{,}000 \times 200 \times 15}{100{,}000{,}000} = 120 \text{ volts.}$$

If the drop in the armature of this machine due to $i\,r$, be five volts, the pressure at its brushes will be 125 volts.

184. The controlling factors in the operation of a motor are its speed, and its torque, and these vary greatly in different cases according to the amount and character of the work that has to be performed. These conditions may be arranged under the following general classes; namely,

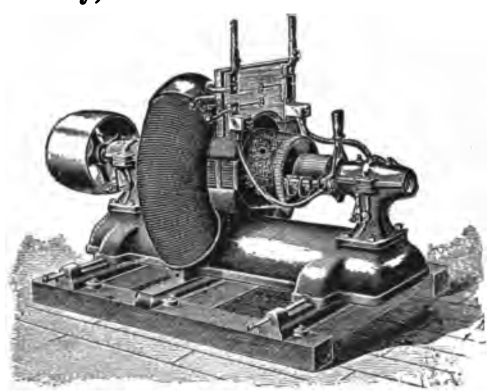

FIG. 78.

(*1.*) Cases in which a constant torque and constant speed are required.

(*2.*) Cases in which a constant torque and variable speed are required.

(*3.*) Cases in which a variable torque and a constant speed are required.

(*4.*) Cases in which a variable torque and variable speed are required.

Instances of the first case are seen in fan motors and in rotary pumps.

Instances of the second case are seen in hoisting machinery, elevators and rollers.

Instances of the third case are seen in most machines and tools.

Instances of the fourth case are street car motors.

185. If the pulley P, Fig. 79, be keyed to the armature shaft of a motor which is turning in the direction indicated by the arrow, it will raise the weight W, and do work. The torque exerted by the pulley will be the weight multiplied by the effective radius of the

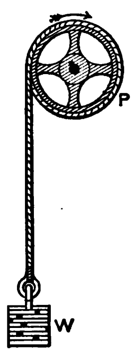

FIG. 79.
Motor pulley lifting a weight.

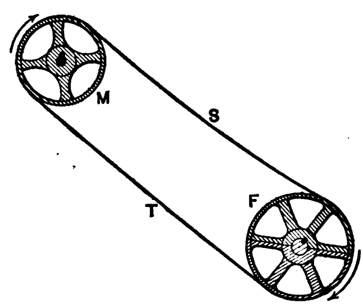

FIG. 80.
Motor pulley driving a pulley P, by means of a belt.

pulley. For example, if the pulley have a diameter of 11 inches, its radius will be 5.5″ and if the rope have a diameter of 1″, the effective radius of the pulley will be increased by half the thickness of the rope; or to 6″ = 0.5 foot. If the weight W, be 500 pounds, the torque at the motor shaft will be $0.5 \times 500 = 250$ pounds-feet. Or, in other words, is equal to the weight of 250 pounds supported at the effective unit radius of one foot. If the motor be employed to lift this weight, the rate at which

it will lift it will be the number of revolutions per second multiplied by the effective circumference of the pulley. In this case, for every revolution of the pulley, the rope will be lifted through the distance of $2\pi \times 0.5 = 3.1416$ feet; and, if the armature makes 20 revolutions per second, the rate of lifting will be 62.832 feet per second. The work done per second, that is, the activity of raising, will be $62.832 \times 500 = 31{,}416$ foot-pounds per second; and, since 550 foot-pounds per second represents the activity of one horse-power, and 737.3 foot-pounds per second represents the activity of one kilowatt, the output of the motor will be $\frac{31{,}416}{737.3} =$ 42.61 KW.

186. If, as shown in Fig. 80, the pulley M, keyed to the motor shaft, drives a countershaft pulley F, by means of the belt S T, which moves in the direction of the arrows, there will be two forces acting on each pulley instead of a single force, as represented in the preceding figure; namely, the forces on the two parts of the belt. One of these, the lower, marked T, is, however the tight or driving side, while the upper, or S, is the slack or following side, and the difference between the two tensions exerted by the belt represents the corresponding equivalent pull of the preceding case. Thus, if the tension on the side T, be equal to 1,000 pounds weight, while the tension on the side S, be equal to 400 pounds weight, the effective pull will be 600 pounds weight, delivered at the periphery or effective radius of the pulley M, while the sum of the tensions or 1,400 pounds, will be exerted in drawing the shafts bodily over against their journal bearings.

The torque exerted by the motor armature is $\frac{i\,\Phi\,w}{10 \times 2\,\pi}$ cm.-dynes, where i, is the current strength through the armature of the motor in amperes; Φ, the flux passing through each pole into, or out of, the armature in webers; and w, the number of wires lying on the surface of the armature, counted once around. Thus, in the case of the motor already considered, if the current through the armature were 50 amperes, the torque exerted by the motor would be,

$$\frac{50 \times 4{,}000{,}000 \times 200}{62.832} = 636{,}700{,}000 \text{ cm.-dynes nearly;}$$

so that, if the effective radius of the pulley were 1 cm., the motor would just exert a force at the periphery of the pulley of 636,700,000 dynes; and, since a dyne is a force equal to 1.0203 milligrammes weight, the motor would just lift 649,600,000 milligrammes = 649.6 kilogrammes = 1,432 pounds weight at an effective radius of one cm., since one kilogramme = 2.205 pounds. For a pulley whose effective radius was one foot, (30.48 cms.), however, the motor would raise $\frac{1432}{30.48} = 46.98$ pounds. In this calculation we have to consider that the rotating motor armature exerts a torque partly expended in overcoming mechanical, electrical, and magnetic frictions, so that the resisting torques due to these causes must be subtracted in order to arrive at the available or useful mechanical torque.

Thus, if the torque exerted by this motor against mechanical friction were 3 pounds-feet, against hysteresis 2 pounds-feet, and against eddy-current electrodynamic forces 1 pound-foot, the mechanical torque at the pulley

when running with 50 amperes through the armature would be 40.98 pounds-feet.

187. In Fig. 81 is represented a case of the transmission of a power of 20 KW. to a distance of one mile, from an engine to a line shaft, with the aid of two

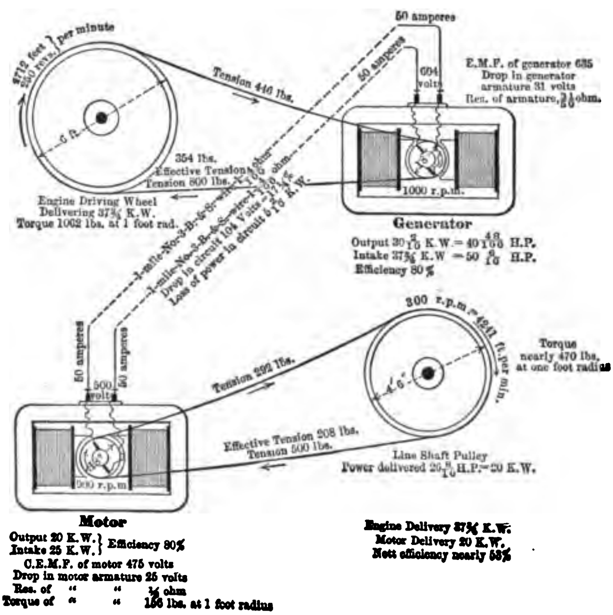

FIG. 81.

similar 500 volt dynamo machines, one employed as a generator, and the other as a motor, their efficiency being taken as 80 per cent., and the net efficiency of the system 53 per cent.

SYLLABUS.

Dynamos and motors are reversible machines, in all cases where suitable means are provided for exciting their field magnets.

In both dynamos and motors electromotive forces and electrodynamic forces coexist. In the dynamo the E. M. F. is direct, or aids the current, while the dynamic force is opposed to the motion, or is a counterdynamic force. In a motor the E. M. F. is opposed to the current, or has a C. E. M. F., while the dynamic force is direct, or exerts rotation.

In the dynamo, the terminal pressure is less than the E. M. F. in the armature. In the motor, the terminal pressure is greater than the C. E. M. F.

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—BY—

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INTERMEDIATE GRADE.

THE ELECTRIC MOTOR.

(CONTINUOUS CURRENT TYPE.)

188. When the torque exerted by a motor, supplied direct from constant-potential mains, is constant, as, for example, when the motor is applied to lifting a weight in an electric hoist (see Fig. 82), and when at the same time the speed of lifting has to be varied, there are practically two ways of obtaining the required variation in speed, viz.,

(*1.*) By introducing a rheostat into the armature circuit, thereby producing a drop of pressure in that circuit, and reducing the C. E. M. F. which the armature has to make up; that is, reducing the speed at which the motor has to run.

(*2.*) By varying the M. M. F. of the field magnets, so as to produce a varying flux through the armature, and, consequently, a varying C. E. M. F.

The first method is capable of being applied over any desired range, but is wasteful of energy. The second method does not waste energy, but is only capable of being practically applied over a limited range.

189. We have seen that the torque of a motor armature is equal to $\frac{i\,\Phi\,w}{20\,\pi}$ cm.-dynes (Sec. 186), including the frictional torque of the armature; consequently, with a fixed armature flux Φ, a given torque requires a definite current strength i, amperes. The energy supplied from the mains to obtain this torque, must, therefore, be $E\,i$ watts, where E is the pressure in the

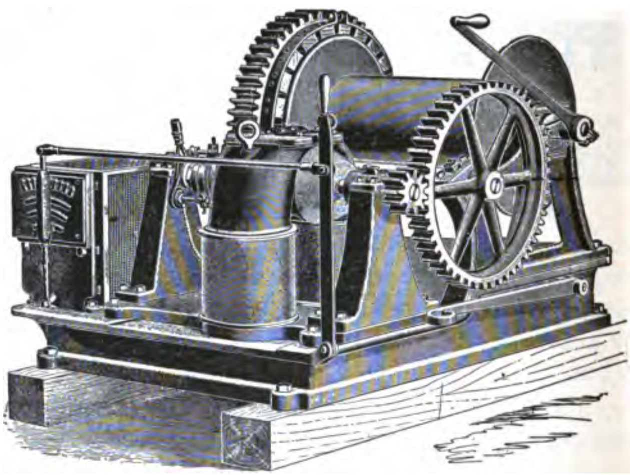

FIG. 82.—SMALL ELECTRIC MINE HOIST.

mains. Consequently, this amount of energy must be taken from the mains, whether the motor does work or not; that is to say, whether it merely exerts the required torque without moving, or, whether it moves and does work at such a speed that the C. E. M F. is nearly equal to E, and no external drop in resistance has to be supplied.

The conditions of operating a motor with external re-

sistance in its circuit, are necessarily unstable, except with a perfectly uniform torque; for, any variation of torque will cause the motor to demand a varied current strength, and the drop in the resistance will correspondingly vary with changes in the current, necessitating a change in the speed and C. E. M. F. of the motor to maintain balance of pressure. Moreover, in large machines, which have to supply a powerful torque, a powerful current may be necessary, and the amount of energy which has to be dissipated in heating the external resistance, when the motor is operating at its lowest speed, may be very considerable, requiring a cumbersome and costly rheostat, in order to carry safely the full-load current, and dissipate the heat generated by the same.

190. If it were possible to vary widely the range of the armature flux in a motor, constant torque could be maintained at varying speeds without waste of energy; for, the torque being equal to $\frac{i\,\Phi\,w}{20\,\pi}$, a large increase in Φ, would necessitate, for the same torque, a correspondingly large decrease in i, the current strength; while, since also $\Phi\, n\, w$, represents the C. E. M. F. of the motor, the same large increase in Φ, would necessitate a correspondingly large reduction in n, the number of revolutions of the armature per second; so that the current and energy absorbed would diminish along with a diminution of speed. Thus, if a shunt motor be operated from constant potential mains at 125 volts pressure, and the full-load current be 100 amperes, so that its full-load intake in the armature circuit is 12.5 KW., the speed of the motor would be 900 revolutions per minute, or 15

revolutions per second, if the resistance of the armature were 0.05 ohm, the number of wires on the armature surface 200, and the total useful flux through one pole 4 megawebers; for, the drop in the armature at full-load, would be $100 \times 0.05 = 5$ volts, and the C. E. M. F. 120 volts, so that $\Phi\ n\ w$ is

$$4{,}000{,}000 \times 15 \times 200 = 120 \times 10^8 \quad \text{the C. E. M. F.}$$

The torque exerted by the armature, would be

$$\tau = \frac{i\,\Phi w}{20\,\pi} = \frac{100 \times 4{,}000{,}000 \times 200}{62.83} = 1.273 \times 10^9 \quad \text{cm.-dynes.}$$

This would be the total torque of the armature including the torque exerted against frictions in the machine. If these constituted ten per cent. of the total, or 0.1273×10^9 cm.-dynes, the available torque at the pulley would be 1.146×10^9 cm.-dynes $= 84.44$ pounds-feet. At full speed the motor would do work at the pulley amounting to $2\,\pi\,n\,\tau$, or $900 \times 6.283 \times 84.44 = 477{,}600$ foot-pounds per minute $= 10.8$ KW., or 14.47 H. P.

If now the flux could be increased tenfold, that is, to 40 megawebers, the same total torque could be obtained with 10 amperes. The armature drop being 0.5 volt, the C. E. M. F. 124.5 volts, the speed would be reduced to 93.4 revs. per minute. The work done at the pulley, with the same allowance for machine frictions, would be 1.12 KW. and the energy absorbed from the mains by the armature circuit 1.25 KW.

In practice, however, the range which is under control is a limited one; the maximum limit of Φ, being set by the rapidly increasing reluctivity of iron at densities approaching saturation, while the minimum limit is established by armature reaction, which seriously dis-

torts the weakened magnet flux, and may even overpower it, causing violent sparking at the brushes, and irregular operation. In shunt machines, the ratio of speed usually obtainable by variation of M. M. F. is about 25 per cent., while in series machines, it may, under favorable circumstances, amount to doubling the speed.

191. The case of variable torque and constant speed is continually met with in practice; for example, when a lathe, drill, planer or other large machine tool, has to be driven at a constant speed by an electric motor under very variable loads. A shunt motor, connected with constant-potential mains, accommodates itself very closely to this requirement; for, neglecting the secondary effects of armature reaction, the only diminution of speed between light and full loads is due to the drop in the armature resistance, representing a fall of speed of, say, 2 per cent. in a 100 KW. motor, and 5 per cent. in a 1 KW. motor. A series motor, however, is very far from complying with these requirements, since an increase in load automatically increases the M. M. F. of the field magnets, thus increasing both the flux through the armature and the C. E. M. F., allowing the speed to diminish, with a further retardation due to drop in the resistance of the machine. Series motors, therefore, are not applicable to cases where a constant speed is automatically required under conditions of variable load.

A compound-wound generator is, however, capable of being directly employed as a compound motor without any change in its electrical connections. The series winding here exerts a counter M. M. F., (abbreviated, C. M. M. F.), and thus diminishes the flux through the armature at full load, thus requiring an increase in

speed, to compensate for the drop in the armature resistance. Such machines are rarely needed, since the regulation in speed obtained by shunt machines is usually sufficient for practical requirements and, moreover, they are simpler to construct.

192. A typical case of variable torque and variable speed is encountered in the electric street-car motor. For the speed has to be varied within wide limits under very varying conditions of torque, according to the number of passengers carried and the gradient of the track. Here the same methods are adopted, as have already been alluded to in dealing with constant torque at variable speed; that is to say, either resistance is inserted in circuit with the armature, or the M. M. F. of the field magnets is varied, or, in some cases, both means of regulation are employed. While these afford sufficient regulation for street car motors, they fail to secure a perfect automatic control of speed under varied conditions of torque; and, in this respect, the electric motor appears to least advantage.

193. In consequence of the reversibility of a generator and motor, the same dynamo electric machine can, as already observed, be employed in either capacity; but its output as a generator, will, with constant excitation and speed, be always greater than its output as a motor. For, suppose a 50 KW. generator supplying a full-load current of 100 amperes at 500 volts terminal pressure. With a given excitation and speed, the frictional losses, magnetic, electric, and mechanical, will, perhaps, amount to 5 KW. These are supplied by the engine when the machine is acting as a generator, with an intake of

55 KW. at the shaft; but, as a motor, at the same speed and excitation, the armature can only maintain a current strength of 100 amperes without overheating, while the frictions must now be supplied electrically so that the output of the machine will only be about 45 KW.

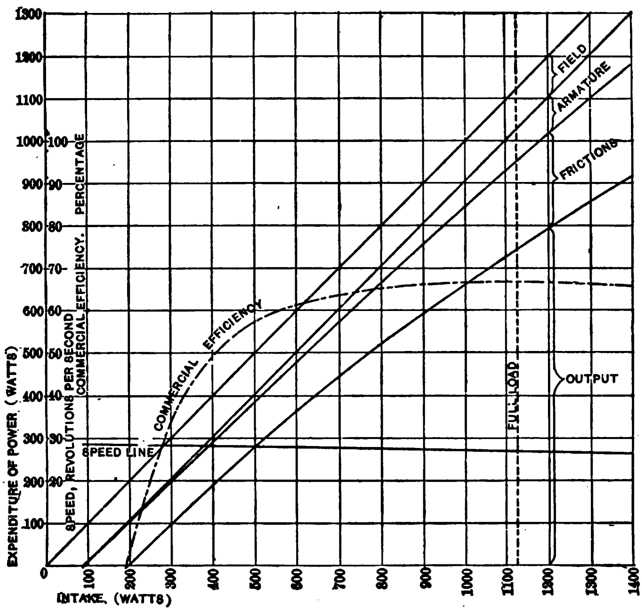

FIG. 83.
Curves showing Expenditure of Power in a 750-Watt Shunt-Wound Motor operated from constant potential mains.

194. Fig. 83 represents curves taken from the test of a particular 0.75 KW. shunt motor, wound for 500 volts. It will be seen that at full load, that is, at a delivery of 0.75 KW. at the pulley, the intake is 1130 watts, representing a commercial efficiency of 66.4 per cent.

Of this 1130 watts, 90 are expended as $i^2 r$, in the shunt field, 70 as $i^2 r$, in the armature, 220 in mechanical, eddy, and hysteretic frictions, leaving the balance of 750 as output.

Syllabus.

The condition of constant torque and variable speed may be obtained by inserting resistance in the circuit of a shunt motor, or by commuting the fields of a series motor.

The condition of variable torque and constant speed is very fairly met by shunt motors supplied from constant-potential mains. It can be still more closely met by compound-wound motors, but is not met by series motors.

The condition of variable torque and variable speed cannot at present be automatically obtained in a single motor operated from constant potential mains.

No. 24.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

THE ELECTRIC MOTOR.

(CONTINUOUS CURRENT TYPE.)

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195. Motor armatures, like generator armatures, are either of the smooth-cored or toothed-cored type. In a smooth-cored armature, the electrodynamic force is largely exerted upon the substance of the wires, so that they are liable to be dislodged by momentarily powerful currents. In the toothed-cored armature, the wires, embedded in iron grooves, merely exert their M. M. F., and direct the flux through the surrounding iron, so that the electrodynamic force is entirely exerted, under the distribution of $\frac{\mathcal{B}^2}{8\pi}$, between the polar surfaces and the surfaces of the iron armature projections. (Sec. 125.)

196. Moreover, the eddy currents that are set up in the substance of the wires, when situated on the surface of a smooth-cored armature, in passing through the field flux, are avoided in toothed-cored armatures, where the flux is bodily guided, from side to side of the buried wires, through the mass of the iron. For these reasons,

motors with toothed-cored armatures are rapidly displacing smooth-cored armatures. Especial care, has, however, to be taken in the design of toothed-cored armatures, in order to prevent excessive sparking, which is liable to be set up at the brushes, by reason of the increased inductance of coils nearly surrounded by iron. (Sec. 137, 160 and 162.)

197. Since the motor armature revolves under the influence of a distribution of flux between the poles and armature, whereby the attractive force is increased on one side and diminished on the other, (Sec. 125) the direction of M. M. F. in a motor armature must be such as will increase, by the flux it produces, the intensity at the polar edge which the armature approaches, i.e., the *leading polar edge*, and decrease the intensity at the polar edge which it leaves, i.e., the *following or trailing polar edge.* We have seen, however, that in a generator, the armature has to be moved by mechanical force, against an electrodynamic force; and, consequently, the leading polar edge in a dynamo is weakened, while the trailing polar edge has its intensity strengthened by the armature reaction and M. M. F. The M. M. F. in a motor armature, is, therefore, opposed to the direction of M. M. F. in a generator armature, when the direction of rotation and the direction of field M. M. F. are the same. This is the key to all the relations existing between the direction of rotation of a machine when acting as a generator or as a motor.

Thus, when the direction of current through the machine, or the direction of E. M. F. at the terminals of the machine, remains the same, a shunt-wound motor will have the same direction of rotation as when employed

as a generator, while a series-wound machine will, on the contrary, have the opposite direction of rotation, as a

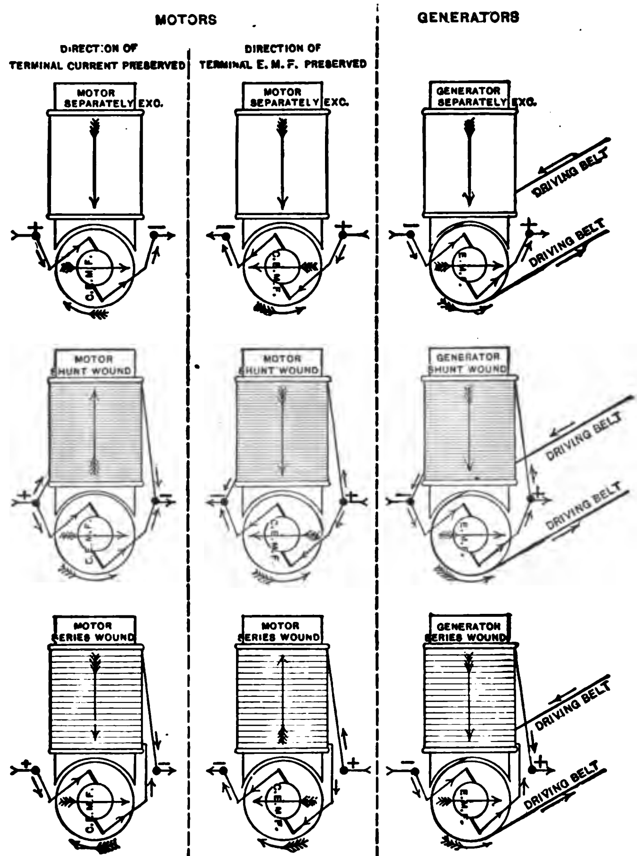

FIG. 84.
Showing Relative Direction of Rotation in Generators and Motors.

motor, that it has when driven as a generator. It also follows that in order to reverse the direction of rota-

tion of a motor it is only necessary to reverse the M. M. F. either of the field magnets, or of the armature, while, if both be reversed, the direction of rotation will remain unchanged. For this reason the mere reversal of the terminals of any motor will not alter its direction of rotation, unless the field magnets are separately excited.

These conditions are exemplified in Fig. 84, where the uppermost row of motors are represented as separately excited, the middle row as shunt-wound, and the lowest row, as series-wound. The large straight arrows indicate the directions of the M. M. F.'s in fields and armatures, while the curved arrows indicate the direction of rotation. The direction of E. M. F. in the armature is also in the direction in which the letters are marked.

198. Motors, like generators, are capable of being operated in series. In practice, however, they require either to be mechanically coupled together, so that they are forced to maintain the same speed, or, their load must be so adjusted that their speed is automatically controlled. If this condition is not complied with, the motors are likely to race, and thus give rise to troublesome irregularities of speed.

199. The advantages which an electric motor possess over other motors may be enumerated as follows.

(*1.*) Facility of reversal of direction of rotation.

(*2.*) Small size and weight per kilowatt (weight average 100 to 180 lbs. per kilowatt of output).

(*3.*) Self governing power, or the capability of automatic control.

(*4.*) A high efficiency.

(*5.*) Rotary as opposed to reciprocating motion, with facility of operation and freedom from repairs.

(6.) Portability in small sizes, when connected with machine tools, so that a tool can be brought to the work, rather than the work to the tool.

(7.) Cleanliness; i.e., protection from dust, liquids, etc.

(8.) Convenience and efficiency of distributing power to distances by means of insulated conductors.

(9.) Facility with which the power can be metered to consumers and observed at any moment.

200. In reversing a motor, it is merely necessary, as we have seen, to reverse the M. M. F. either of the field magnets, or of the armature, and, in practice, it is usually the armature which is so reversed. It is necessary, however, to avoid making the reversal suddenly, unless resistance be temporarily inserted in the armature circuit, for the reason that the momentum of the armature, carries it in its previous direction, and the E. M. F. of the armature under such conditions is no longer a C. E. M. F. to the circuit, but is a direct E. M. F. (contracted D. E. M. F.) tending to increase the current strength that will flow through the armature, when connected with the mains. Thus, suppose a 10 KW. 120-volt shunt-motor, with 100 amperes full-load intake, making 1,000 revolutions per minute, is connected to a system of mains, maintaining a constant pressure of 120 volts. On cutting off the current from the armature, whose resistance may be 0.05 ohm, the motor may take, say, sixty seconds to come to rest, depending upon the amount of load to which it is connected. If, however, while still running at 500 revolutions per minute, the armature be connected reversed to the mains, the E. M. F. of the armature will be 60 volts in the same direction as the E. M. F. now impressed from the mains, so that the cur-

rent strength which would pass through the armature according to Ohm's law would be $\frac{120 + 60}{0.05} = 3{,}600$ amperes, or 36 times greater than the normal, full-load intake. Of course the inductance of the armature would tend to set up a temporary C. E. M. F., independently of the rotation of the armature, tending to check this rush of current, but it is easy to see that before the momentum of the armature can be overcome, and its C. E. M. F. established by acceleration in the opposite direction, a dangerously strong current may pass through it. This shows that either resistance, or inductance, or both, should be inserted in the circuit of the armature of a motor when it has to be reversed.

The same necessity for avoiding excessive rush of current exists, although to a smaller degree, in starting shunt motors from rest. A *starting rheostat*, therefore, has generally to be introduced, especially with large motors, in order slowly to accelerate the armature and develop its C. E. M. F. For this reason series motors can be more safely started from rest suddenly, owing to the resistance and inductance of the field magnet coils, which automatically check the first rush of current through the machine before the C. E. M. F. has had time to develop.

201. In electric locomotors, it is essential that the weight should be reduced as far as possible. The torque to be exerted by such a motor varies with the weight to be moved, the friction of the track, and the gradient. Fig. 85 represents a motor shaft M, geared directly to the car wheel W. A motor used in connection with such gearing is commonly called a *single reduction motor*.

If the pull, which would have to be exerted upon the car in a direction parallel with the track, be P, lbs., due to gradient and friction combined, then the torque at the axle of the car W, will be $P\,f$ lbs.-feet, where f, is the radius of the car wheel (usually 1.25 feet in a street car). If j, be the gearing ratio of the motor and wheel, so that the motor makes j revolutions to each revolution of the car wheel, the torque at the motor shaft will be $\frac{P\,f}{j}$ lbs.-ft. It is necessary, therefore, that the torque

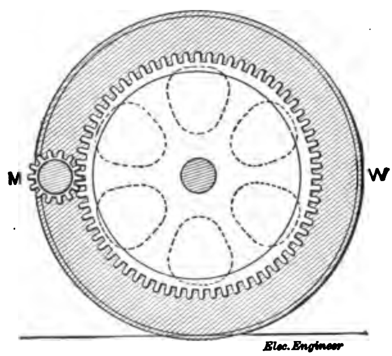

FIG. 85.
Single Reduction Gear between Street Car Motor and Car Wheel.

$\tau = \frac{i\,\varphi\,w}{20\,\pi}$ cm.-dynes, which the motor can exert with the maximum permissible current i, amperes, shall be equal to $\frac{P\,f}{j}$ lbs.-ft. for the maximum gradient and friction which the car has to overcome. Since the weight of the motor adds to P, it is necessary to obtain the maximum amount of torque from the motor, with the smallest weight consistent with perfect mechanical security, freedom from sparking, and other difficulties.

This is accomplished in practice, for street cars and railway motors, by employing toothed-cored armatures, carbon brushes, and cast steel multipolar field magnet frames, so that the maximum flux is obtained with the minimum material.

SYLLABUS.

Smooth-cored armatures are mechanically weaker than toothed-cored armatures.

The relative directions of M. M. F. in armature and field, for the same direction of rotation, are reversed in motors and generators.

The leading pole edge has its flux density strengthened in a motor, and the trailing polar edge has its flux density strengthened in a generator by armature M. M. F.

It is essential to introduce resistance or inductance into the armature circuit of a motor which is being reversed or started from rest.

No. 25.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ELECTRIC HEATING.

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202. The universal result of the passage of an electric current through a conductor is the generation of heat in the substance of the conductor. We have seen, (Secs. 57 to 60) that the passage of a current of I amperes, through a resistance of R ohms, develops in the conductor a C. E. M. F. of $E = I\ R$ volts drop. The work done by the current against this C. E. M. F. appears as heat in the resistance, and is equal to $E\ I$ joules per second, or a thermal activity of $E\ I = I^2\ R$ watts.

203. Careful determinations have been made as to the increase of temperature produced in a given mass of water by a given quantity of heat. It has been found that approximately 4.18 joules of energy, expended as heat, will raise the temperature of one gramme of water from 3° C. to 4° C. (and approximately 1° C. at any temperature between the freezing and the boiling points). This unit quantity of heat is called indifferently the *lesser calorie*, the *gramme calorie*, the *therm*, or the *water-gramme-*

degree-centigrade. A definite relation exists between the amount of heat required to raise a gramme of water, and a gramme of any other substance through a given range of temperature. The amount of heat required to raise the temperature of one gramme mass of a substance 1° C., referred to that required to raise the same mass of water as unity, is called the *specific heat* of that substance. Thus, the specific heat of copper is 0.093, so that the amount of heat required to raise a given mass of copper through a given range of temperature is 9.3 per cent. of that required to raise the same mass of water through the same range of temperature.

If 50 joules be expended uniformly as heat in one pound of copper (453.6 grammes), each gramme will receive $\frac{50}{453.6} = 0.1102$ joule. One gramme of water would be raised by this amount of heat $\frac{0.1102}{4.18} = 0.02637°$ C., and one gramme of copper, having less capacity for heat, would be raised about ten times more, or through $\frac{0.02637}{0.093} = 0.2835°$ C.

Electrically generated heat is commercially employed in furnaces for the reduction, refining and melting of refractory metals and ores, for welding, for artificial heating and for cooking.

204. One gramme of good coal is capable, when burned, of producing 33,500 joules. The average efficiency of a good compound engine and boiler, such as are employed in central stations may practically be taken as 0.12. The average efficiency of the generators directly connected with such engines may be taken as 0.9, and the mean efficiency of the transmission systems of mains in low tension systems, including house wiring about 0.9.

The net efficiency of the entire transmission plant to the supply terminals is, therefore,

$$0.12 \times 0.9 \times 0.9 = 0.0972,$$

so that the amount of energy obtainable as heat from one gramme of coal in an electric heater at a distance of, say, half a mile from a central station, is 3,256 joules.

Although the efficiency of electrically distributed heating is, therefore, under practical conditions, less than 10 per cent., yet, where a small quantity of heat is to be employed, as in cooking ranges, the efficiency may be higher than in the ordinary cooking stove or range, the efficiency of which is probably at best only 6 per cent., for the reason that in ordinary stoves most of the heat energy passes out of the chimney in warm air and unburnt gases. Moreover, the question of time enters into the relative advantages, since the electric stove can be started and stopped in operation immediately, whereas a cooking fire requires time both for starting and for stopping.

205. As regards its construction, an electric heater consists essentially of a resistance coil, usually of galvanized iron, German silver, or other suitable alloy, closely surrounded with thermally conducting material in order to communicate the heat developed in this resistance to the body of the heater. Or the wire is embedded in a mass of vitrified clay, or of enamel. A form of such heater applied to a teapot is shown in Fig. 86, arranged for connections to mains of 50 volts or 110 volts alternating or continuous current pressures.

206. The losses of heat from an electric furnace or cooking range can be made comparatively small, since the entire apparatus can be lined with a thermal

non-conductor, such as asbestos, or an air jacket, and no draught of air has to be supplied through the apparatus as in the case of a combustion furnace.

The amount of energy required to heat up to boiling point (100° C.) a U. S. gallon of water (3786 c.c.) from an initial temperature of 5° C. (41° F.) is approximately $95 \times 3786 \times 4.18 = 1{,}503{,}000$ joules. The cost of electrical energy, when supplied in small quantities, from the street mains in large cities, is usually about 15 cents per kilowatt-hour (1,000 watts during 3,600 seconds, or 3,600,000 joules) so that the cost of heating one gallon

Fig. 86.
Electrically Heated Tea Pot.

of water to the boiling point, assuming no loss in the heater, is about $6\frac{1}{4}$ cents. The practical efficiency of electric heaters is seldom so low as 50 per cent., and may under specially favorable conditions, reach 95 per cent., so that at an efficiency of 70 per cent., the cost of boiling a gallon of water by electrically distributed heat, on a small scale, amounts to about 9 cents. This is much more expensive than the cost of the same operation in a combustion range, and the price of the electric heater is at present also greater than the price of a gas, coal, or oil heater, but the greater simplicity, convenience and

cleanliness of the electric heater for culinary purposes on a small scale often outweighs its greater expense.

An electric car heater, supplied at 500 volts pressure, requires from 2 to 12 amperes, according to the size of the car, and the coldness of the weather.

207. An incandescent lamp is an instance of the application of electric heating to the attainment of that temperature in carbon at which it emits luminous radiation. Unfortunately in order to obtain this luminous radiation a very large amount of non-luminous radiation has to be produced. Thus, from the glowing filament of an ordinary 16 C. P. incandescent lamp, about 50 joules of thermal energy are emitted per second, and only about 5 per cent. of this or 2.5 joules are emitted as luminous radiation, the remainder leaving the filament either in non-luminous radiation, or in energy communicated to the molecules of the gas remaining in the globe.

208. It is a common observation that wires carrying electric currents frequently become intensely heated. This is because their resistance per cm., or per foot, causes the current they carry to develop as $i^2 r$, so many joules of heat per second in their mass, that a high temperature has to be reached before the losses of heat by radiation and convection can keep pace with the rate of development. Until this equality of output and intake are attained, the temperature of the wire will be increasing.

209. A wire of bare copper or iron, suspended in air, when heated by a steady current, theoretically requires an indefinitely long time to acquire its maximum temperature, but practically, owing to the freedom with

which the heat is carried away by convection in the surrounding air, the full elevation of temperature is attained in about five minutes. When, however, the wire is insulated, and laid in wooden moulding, as in the case of house wires, about 95 per cent. of the full increase in temperature is usually attained in ten minutes. When the wires are buried in the ground, the temperature may continue to rise, with large cables, for many hours, but with copper conductors of less than one cm. in diameter, about 95 per cent. of the maximum temperature elevation is usually attained in twenty minutes after the application of the current.

210. The amount of heat generated in a wire for a given effective current strength, as measured by a properly calibrated ammeter, is the same, at all ordinary commercial frequencies and practically employed sizes of wire, whether the current be continuous or alternating. In the case of very high frequencies and large wires, the resistance of the circuit to alternating currents is greater than that they offer to continuous currents, owing to what is termed the "skin effect" and, therefore, the amount of heat developed in such cases in the wires would be greater for alternating than for continuous currents.

211. The following table gives the diameters of copper wire, which will be raised approximately 20° C. (36° F.) by the current strengths shown, under various conditions, such, for example, as in wooden moulding, or in air, within doors or out of doors. Such a wire would be raised to 50° C. from an initial temperature of 30° C., and a wire at a temperature of

50° C. can be handled without discomfort. Such a diameter would therefore be safe to employ in buildings, but would not allow a sufficient margin of safety for accidental overload. For this reason, the limiting safe temperature elevations and current strengths hitherto

TABLE OF DIAMETERS OF COPPER WIRE, OF CONDUCTIVITY 98 PER CENT. MATTHIESSEN'S STANDARD, ELEVATED 20° C. BY VARIOUS CURRENT STRENGTHS IN AMPERES (ALTERNATING OR CONTINUOUS).

Effective Current Strength Amperes.	Covered Wire in Wooden Moulding.	Bare Wire Suspended Horizontally in Still Air Within Doors.		Bare Wire Suspended Horizontally in *Calm* Weather Out of Doors.	
		Bright.	Blackened.	Bright.	Blackened.
	Inches.	Inches.	Inches.	Inches.	Inches.
5	0.020	0.015	0.014	0.011	0.010
10	0.036	0.030	0.028	0.022	0.020
15	0.052	0.045	0.042	0.032	0.030
20	0.069	0.060	0.057	0.042	0.039
25	0.085	0.075	0.068	0.052	0.049
30	0.100	0.090	0.080	0.061	0.058
35	0.114	0.103	0.092	0.070	0.066
40	0.127	0.115	0.105	0.079	0.074
45	0.140	0.128	0.117	0.087	0.082
50	0.152	0.140	0.130	0.094	0.089
60	0.175	0.168	0.152	0.108	0.103
70	0.197	0.190	0.171	0.122	0.116
80	0.218	0.212	0.192	0.134	0.128
90	0.236	0.235	0.210	0.146	0.140
100	0.254	0.257	0.227	0.157	0.151
125	0.292	0.307	0.265	0.183	0.175
150	0.326	0.365	0.308	0.210	0.202
175	0.357	0.410	0.347	0.234	0.227
200	0.386	0.450	0.385	0.256	0.248
250	0.440	0.520	0.455	0.299	0.290
300	....	0.615	0.518	0.339	0.330
400	....	0.765	0.640	0.418	0.406
500	....	0.910	0.750	0.488	0.471
600	....	....	0.857	0.550	0.533
700	....	....	0.958	0.611	0.593
800	....	....	....	0.671	0.650
900	....	....	....	0.717	0.693
1000	....	....	....	0.782	0.745

adopted by fire insurance authorities are considerably lower, corresponding to about 10° C. temperature elevation at full load and with a reduction of about 33 per cent. in current strength.

212. The sudden heating effect of excessive currents is practically employed in fuse wires, which are always connected in circuits in order to protect the wires or apparatus in those circuits from excessive current strength. These wires or strips are usually composed of alloys of tin and lead, so as to possess a high resistivity and a low melting point. A high resistivity enables an amount of heat to be generated in them per square centimetre of cross-section, sufficiently great to produce the fusing effect desired.

A safety fuse is generally so proportioned as to melt at 50 per cent. overload. Thus, when a full-load current which a wire has to carry is 50 amperes, it is usual to place in circuit with it a safety fuse of 75 amperes fusing current.

Syllabus.

The passage of an electric current against the C. E. M. F. established in a resistance, does work at the rate of $i^2 r$ watts or joules per second, which appears as heat in the resistance.

The same amount of heat is practically produced in the same wire by a given effective current strength, whether the current be alternating or continuous.

For small cooking stoves electric heating is more efficient and more convenient, although at the present time more costly.

No. 26.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

INCANDESCENT LIGHTING

213. An incandescent lamp consists essentially of a filament of refractory material, almost invariably carbon, electrically heated to incandescence and protected from oxidation by enclosure within a sealed and exhausted glass globe.

The manufacture of an incandescent lamp consists essentially of the following steps,

(*1.*) The manufacture of the filament.

(*2.*) The connection with the leading-in wires and support within the glass globe.

(*3.*) The obtaining of the proper vacuum.

214. Different processes have been devised for obtaining the material of the carbon filament. Briefly, they are as follows: A suitable carbonizable material, after being properly shaped, is subjected to carbonization under the prolonged action of a high temperature while out of contact with air. The time required for the heating and cooling of a set of filaments of carbon

in a furnace may be two days. The following materials have been employed for this purpose; viz., loosely spun cotton thread cleansed from grease either in its natural state or parchmentized by the action of sulphuric acid; selected bamboo fibre; celluloid, silk thread and various carbonacous liquids or carbonacous pastes. There are thus obtained slender threads or filaments of the required dimensions, possessing sufficient rigidity and elasticity to stand mounting, transportation and vibration while in use. For actual use the carbon filament must be homogeneous in structure, and must possess uniform electrical resistance per unit length, since, otherwise, when heated by the current, it would glow unequally and only parts could be safely heated to the temperature of illumination.

215. The leading-in wires, that is, the wires that carry the incandescing current to the filament, are almost invariably made of platinum, since the similarity in the coefficients of expansion of platinum and glass, enables the platinum wire to be fused into the glass and subjected to fairly wide changes of temperature without endangering the vacuum through subsequent expansions and contractions. Moreover, the high melting point of platinum, permits the glass to be fused around it without being destroyed.

Various methods are employed for connecting the ends of the filament with the ends of the leading-in wires. In all cases, however, two requirements exist; namely, that the connection is electrically good, and that the resistance of the ends of the filament, where they are connected to the wires, is such as to prevent excessively high temperature being attained at the joints.

This is avoided either by lowering the resistance of the joint or by the thermal conductance of the wires.

216. The mounted filament is now subjected to a process called the *flashing process*, for the purpose of producing a more durable carbon surface. The flashing process is conducted briefly as follows: the mounted filament is electrically heated to a dull red, while surrounded by a hydro-carbon vapor, and the current strength is gradually increased. At first, the carbon may glow unequally, the points of highest resistance first reaching incandescence and receiving a deposit of carbon, which tends to reduce the resistance at that spot. The current then being increased, the deposit is caused to be formed gradually over the entire surface of the filament, thereby rendering its resistance uniform throughout, until, when a certain maximum current strength is passing, the filament glows uniformly and emits the required candle power. The entire flashing process requires but a few seconds to complete. A flashed filament is thus provided with a coating of carbon, which possesses greater durability at high temperatures than unflashed carbon.

217. The mounted filament is now introduced into the lamp, and its glass support P, (Fig. 87) fused to the lamp bulb, thus hermetically sealing the lower end of the lamp chamber.

The lamp chamber is now placed in connection with a vacuum pump, by means of an open glass tube at the top of the globe, and exhausted. The best results in regard to efficiency and durability are obtained with the highest vacuum. In order to obtain this, it is

necessary to heat the body of the lamp chamber in order to drive off the film of condensed gas or air adhering to the glass, and also to heat the filament to drive out the occluded gas. Both of these heatings are generally obtained by submitting the lamp to the action of the current during the final stages of exhaustion. The lamp is then hermetically sealed at its tip T, by the fusion of the glass and removed from the pump.

The platinum leading-in wire is made as short as possible and occupies the length J *j*, J *j* as shown, the free ends of the platinum wires, being welded to copper

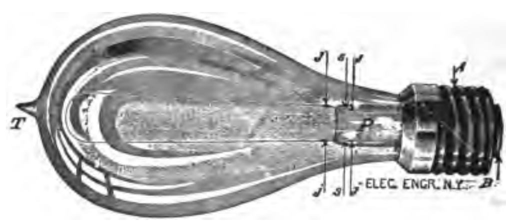

FIG. 87.
16 C. P. Incandescent Lamp.

wires. These copper wires are soldered to the base A, one wire being connected to the external brass screw shell A, and the other to the brass base B, these two parts being insulated from each other by plaster of Paris. Different forms are given to the lamp bases, according to the lighting system used.

The bases shown in Fig. 88 are in common use. A, is a standard Edison base; B, is a Thomson-Houston or old Sawyer-Man base; C, is a Westinghouse, or new Sawyer-Man base; D, is a United States base. In all cases the arrangement is such that merely placing the lamp in a socket connects it with the mains.

218. The amount of activity absorbed by an incandescent lamp in watts, when connected to supply mains at a steady pressure of E volts, is $\frac{E^2}{R}$ watts, where R is the resistance of the lamp when hot. The energy expended by the lamp will be Sp watts, where S, is the surface of the filament in square inches, or square centimeters, and p, the corresponding emissivity in watts per square inch, or per square centimetre, for the particular

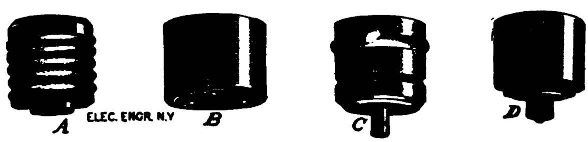

FIG. 88.

Standard Forms of Lamp Base. A, Edison; B, Thomson-Houston; C, Westinghouse; D, United States.

temperature at which the lamp is to be operated. Consequently, since the intake must be equal to the output,

$$\frac{E^2}{R} = Sp.$$

The surface area provided for the filament S, is determined from the number of candles which the lamp has to supply, the quality of the carbon surface, and the temperature at which the lamp is to be operated; so that, when the quality and temperature are fixed, the surface increases with the candle-power. The cross section and length of the filament must, therefore, be so chosen for the resistivity of the material, that the required resistance R, and the required surface S, are obtained. The resistivity of lamp filaments is usually about 0.004 ohm, except for flashed carbon; which has a lower resistivity.

The temperature coefficient of filament carbons is negative (Sec. 32), but that of flashed carbon is positive at incandescent temperatures. A heavily flashed filament may therefore increase in resistance as its temperature is increased beyond that of normal incandescence.

219. When a very feeble current is sent through a lamp, it emits no light, all its radiation being non-luminous or heat radiation. The activity which is expended in the lamp, in such cases, is wasted so far as illumination is concerned. Increasing the current strength through the lamp, the temperature of the filament increases and the lamp commences to glow, the useful proportion of luminous radiation increasing rapidly with the temperature. The incandescent lamp, therefore, produces its greatest illumination efficiency, with the highest safe temperature at which it is possible to operate it.

220. The candle-power of a light is measured in different units in different countries. In America and Great Britain, the *standard candle* is employed. In France, the *carcel lamp*, the *Violle*, or molten platinum lamp, and a candle called the *bougie decimal*, which is $\frac{1}{20}$th of the Violle, are employed. In Germany, the *Hefner-Alteneck lamp*, burning amyl acetate, is employed.

221. The *efficiency* of an incandescent lamp is frequently incorrectly stated as being equal to the number of watts absorbed by the lamp, divided by the number of candles; that is, the number of watts per candle, so that the efficiency thus stated would be higher, the greater the waste in the lamp. The more correct expression is the number of candles divided by the number of watts absorbed, or the candles per watt.

Lamps are usually operated at one of three efficiencies; namely, at

$\frac{1}{3.13}$ candle per watt; so that a 16 candle-power lamp absorbs 50 watts.

$\frac{1}{3.6}$ candle per watt; so that a 16 candle-power lamp absorbs 57.6 watts.

$\frac{1}{4}$ candle per watt; so that a 16 candle-power lamp absorbs 64 watts.

Under ordinary circumstances, therefore, the advantage of an efficiency of $\frac{1}{3.1}$ candle per watt amounts in economy of energy $22\frac{1}{2}$ per cent. over a lamp of $\frac{1}{4}$ candle per watt. For the same quality of carbon employed, the high efficiency lamp has to be operated at a higher temperature and its lifetime is, therefore, considerably reduced. Thus, a lamp, which is operated at an efficiency of $\frac{1}{4}$ candle per watt, may last, on an average, say 5,000 hours; while the same lamp, if operated at such an increase in voltage as will cause its temperature and candle-power to rise, and its efficiency to reach $\frac{1}{3.1}$ candle per watt, may last, on an average, only 800 hours, owing to the more rapid disintegration of the filament at the higher temperature.

At an efficiency of $\frac{1}{4}$ candle per watt, incandescent filaments give a luminous intensity of from 100 to 150 candles per sq. in. of surface (15.5 to 23.25 candles per sq. cm.). At $\frac{1}{3}$ candle per watt the intensity varies between 160 and 270 candles per sq. in. (24.5 and 42 candles per sq. cm.)

222. Incandescent lamps are made in sizes ranging from $\frac{1}{4}$ candle-power up to 100 candle-power. Very small lamps are operated at a low efficiency, say $\frac{1}{8}$ candle per watt, owing partly to the rapid conduction

of heat from the short filaments by the leading-in wires. Such small lamps are only operated by batteries.

The common candle-powers for incandescent lamps are 8, 10, 16, 20, 32, 50, and 100 candles.

Single-filament incandescent lamps, are made for operation on pressures varying from 50 to 220 volts. The lamps of highest pressure are at present only employed at somewhat lower efficiency.

An incandescent lamp gives the same amount of light when connected to alternating or continuous current mains at the same effective pressure.

SYLLABUS.

The filament of an incandescent lamp is made of carbon enclosed in an exhausted glass globe and heated electrically to incandescence.

By flashing a carbon filament, its surface is rendered homogeneous and durable.

In exhausting an incandescent lamp both the filament and bulb are heated to aid in expelling condensed or occluded gas.

The emissivity of the surface of a carbon filament at an efficiency of $\frac{1}{3.1}$ candles per watt varies between 24 and 42 candles per sq. cm.

The efficiency of a lamp is commonly expressed in watts per candle, but should be expressed in candles per watt.

No. 27.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

INCANDESCENT LIGHTING

223. By the illumination of a body is meant the amount of light received by it per unit of surface area. Calling the body giving the light the illuminating body, the body receiving the light, the illuminated body, and the amount of light received per unit of area, the illumination, or the intensity of incident light, then, if the light given by the illuminating body is assumed to be concentrated at a point, the intensity of light received by the illuminated body will be inversely proportional to the square of its distance from the illuminating body. No name has yet been generally adopted for the unit of illumination, although the terms *carcel-metre* and *candle-foot*, have been proposed and are in limited use. The illumination of one *carcel-metre* is the amount of illumination received by a surface perpendicular to the rays of light from one carcel, at a distance of one metre. One carcel-metre = 0.883 candle-foot, so that one candle produces at a distance of a foot an illumination 13 per cent. in

excess of that produced by a carcel at a distance of a metre. The illumination of one carcel-metre upon the surface of a printed page, is amply sufficient for the purposes of reading by the normal eye.

In practice it is difficult to determine by calculation the illumination at any surface in a room, when the position, candle-power and number of incandescent lamps in the room are assigned, owing to the influence produced by the nature and color of the walls, ceilings, draperies and furniture in the room. The amount of light reflected or diffused from the surface of light colored wall-paper is frequently 40 per cent., the remaining sixty per cent. being absorbed by the paper. Usually, however, it is found that $\frac{1}{3}$ candle per square foot of floor space (3.6 candles per square metre) distributed in electric lamps, provides ample illumination for reading rooms, representing one 16 candle-power lamp for every 50 square feet of floor surface. In ordinary rooms, not devoted exclusively to reading, half this amount of illumination, or one 16 candle-power lamp to 100 square feet of floor space will suffice.

224. The effect of continued use of an incandescent lamp even when the pressure supplied to it does not exceed that for which the lamp was designed, is to decrease the diameter of the filament; and, consequently, to increase its resistance. This decrease in the thickness of the filament is due to the wasting away of its surface layers.

A lamp which when first used has an efficiency of, say $\frac{1}{3}$ candle per watt, gradually decreases in efficiency, until, after 1000 hours, its efficiency may only be $\frac{1}{6}$ candle per watt.

225. Lamps are generally guaranteed to last 600 hours under conditions of normal operation, that is, when not operated above the pressure for which they were designed. Their average life depends entirely upon the temperature at which they are worked. At an exceedingly high temperature, perhaps 1380° C., when the interior of the lamp appears bluish, the brilliancy of incandescence is very marked, and the efficiency, measured in candles per watt, very high, say 1.25 candles per watt, but their life may be only one hour. On the other hand, a lamp operated at a dull red, gives very little light and has a low temperature, perhaps 1200° C., with an efficiency of, perhaps, $\frac{1}{20}$ candle per watt, but will continue to burn at this rate almost indefinitely. The average life time of a properly constructed lamp, therefore, depends upon the temperature at which it is designed to operate initially, that is upon its normal efficiency, and a high efficiency lamp is only attained, other things being equal, at the expense of its life time.

A lamp which has been burning at a gradually decreasing efficiency, for, say 1000 hours, may at length have its chamber become so blackened by continued deposition of carbon, that from this cause, together with the concomitant reduction in the emission of light, it may become unserviceable, and it may be cheaper to destroy the lamp and replace it by a new one than to continue its use. The exact period at which it becomes economical to do this is very difficult to decide. In large central station practice, it is usually considered that lamps are properly operated in regard to their pressure, when the cost of lamp renewals amounts to 15 per cent. of the total operating expenses; but, in a single installation, no fixed

rule can be laid down, since, if ample light has been provided at the outset a fairly marked decrease in the light attending increased age of the lamps, will not be objectionable and it may be economical to retain lamps for a very long period.

226. It has been established by actual practice up to the present time, that where a densely lighted district can receive incandescent lighting distribution from a central station near its centre, it is more economical to employ low-tension, multiple-connected systems, on either the two-wire, three-wire, or five-wire plant, but, on the contrary, where the lighting is scattered over a large district, and where the distances to be covered are great, the cost of conductors required for low-tension lighting becomes excessive, and a high-tension system imperative. For street incandescent lighting, under such circumstances, the lamps can be connected to the line in series, like series arc circuits; but where interior lighting has to be provided, it is almost always carried out by the use of alternating current, high-tension, systems, with step-down, local, transformers. In some cases incandescent lamps are required to be operated in arc circuits, in which case they have to carry a current strength of about 10 amperes. For the same output and efficiency, the pressure at such a lamp, of say 16 candles, would be approximately six volts, and its filament would have, when hot, a resistance of about ½ ohm, requiring, therefore, a short thick carbon.

227. With series-connected lamps, in order that the failure of a single lamp shall not open the entire circuit, it is necessary that some device should be pro-

vided for maintaining the continuity of the circuit when any lamp fails. This is usually obtained by means of a cut-out, which short circuits the lamp as soon as the pressure at the lamp terminals exceeds that required for its ordinary operation.

Since an ordinary gas-burner of 16 candle-power consumes about 5 cubic feet of gas per hour, the cost of supplying light electrically in a 16 candle-power incandescent lamp, including the cost of renewing the lamp when it becomes broken or disabled by age, has to be

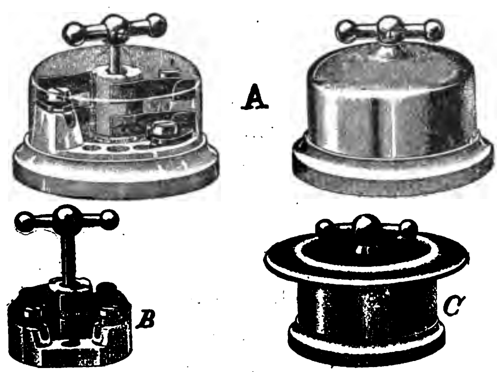

FIG. 89.
Forms of Ratchet Snap Switches.

compared with the cost of 5 cubic feet of gas in order to determine the relative economy of the two illuminants, apart from all considerations of safety, health and convenience. Thus the incandescent lighting rate of $\frac{3}{4}$ cent per 16 C. P. lamp-hour, including lamp renewals, is equivalent to gas at $1.50 per thousand cubic feet.

228. Incandescent light switches, for multiple-connected incandescent lamps, are either single-pole or double-pole. A single-pole switch is similar in con-

nection to the key of the ordinary lamp socket, and merely breaks the circuit at one point. A double-pole switch interrupts the circuit of the lamp or lamps it controls, on each side of the circuit; i.e., breaks both the positive and negative connections. Forms of ratchet snap switches are shown in Fig. 89. A, is a 25-ampere switch. B and C, are 10-ampere switches, that is to say, the maximum current they are intended to carry is 10 amperes.

229. In all multiple incandescent systems the pressure has to be maintained as nearly uniform as possible. Consequently, the drop of pressure in the supply main has to be kept within narrow limits.

Specifications for the sizes of wire employed in wiring buildings for incandescent lighting, usually require that the drop in pressure shall not exceed 3 per cent. of the pressure at the generator terminals, if the building contains its own generator, or of the pressure at the entrance mains, if the building is supplied from street conductors. In large buildings, with many lamps and long distances to be covered by wiring, the limit of drop may be increased to 5 per cent., at full load. Under these circumstances, if the lamps be supplied for the mean pressure in the building, the most distant lamps will be operated at about 2½ per cent. below, while the lamps nearest to the generator or street mains will be about 2½ per cent. above pressure.

230. Various devices have been employed in order to reduce the candle-power of a lamp by turning it down, as can be done with any ordinary gas burner. All such methods have, however, hitherto required that

a resistance, or its equivalent, be introduced into the circuit of the lamp, thereby reducing its current and

FIG. 90.
Theatre Dimmer.

temperature. Under these circumstances, while the lamp gives less light, its efficiency is lowered and the the color of its light is much duller, whereas the color of the gas flame is scarcely affected by turning it down.

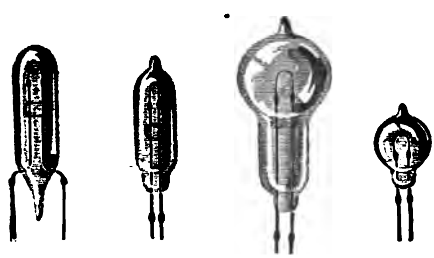

FIG. 91.
Ordinary Forms of Miniature Lamps.

Large resistances are sometimes employed in reducing the candle-power of lamps for scenic effects in theatres.

During the time that the light is reduced, the activity of the lamps is always reduced in much smaller degree, so that the efficiency of the remaining incandescence is very low. Fig. 90 represents a form of theatre dimmer, about one foot square, consisting of a wire resistance embedded in enamel laid upon a metal plate.

Fig. 91 represents the ordinary forms of miniature incandescent lamps as employed for microscopical and surgical purposes.

Syllabus.

The illumination of a body is the amount of light it receives per unit of surface area.

The efficiency and candle-power of a lamp diminishes with use, owing to the reduction of the cross-section of the filament, the change in the surface of the filament, and the blackening of the globe.

The usual amount of drop permitted in incandescent street mains is five per cent. of the central station pressure, and the usual amount of drop in the wiring of buildings varies from two to five per cent., according to the size of the building.

No. 28.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

ARC LIGHTING.

231. The carbon voltaic arc is produced by sending a sufficiently strong current through two carbon electrodes, which are at first in loose contact and are afterwards gradually separated to a short distance. When the current is sufficiently powerful, the space between the ends of the electrodes is filled with incandescent carbon vapor, in the form of a luminous bow, which, from its shape, is called the *voltaic arc*. The carbon vapor is disengaged mainly from the end of the positive carbon, which soon thereby becomes hollowed out in the form of a minute crater.

232. To produce and maintain the voltaic arc, a certain electric activity is necessary, depending upon the distance between the electrodes, their magnitude, position and incandescent surfaces. The average arc, as employed in the U. S. for commercial lighting, requires a current of about 10 amperes, and a total pressure at lamp terminals of about 45 volts, representing an activity of 450 watts. Of the total C. E. M. F. of 45 volts, from

38 to 40 volts are developed at the surface of the positive electrode, about five volts are developed in the arc itself, and the remainder are developed in the resistance of the lamp mechanism. The activity at the surface of the positive carbon is, therefore, from 380 to 400 watts, and this is the principal source of radiant energy.

233. In an electrolytic cell, a C. E. M. F. is set up at the surface of the electrode, and the value of this C. E. M. F. is practically independent of the C. E. M. F. due to the resistance of the intervening liquid, so that work is expended in liberating the products of electrolysis. The development of C. E. M. F. in the arc lamp, is analogous to the development of C. E. M. F. by electrolysis; and, in point of fact, the voltaic arc with its carbon electrodes, forms a species of electrolytic cell, the carbon vapor being analogous to the electrolyte. The energy is here expended in volatilizing carbon at an extremely high temperature, estimated at 3,500° C.; in fact the temperature, which can be attained by means of the electric arc, is probably greater than can be obtained in any other way. The C. E. M. F. of an arc lamp is practically the same for the same distance between the carbon points for all dimensions of carbon electrodes, or areas of incandescence. But the larger the carbon, and the greater the surface of incandescence, the greater the current strength that must be supplied to it. For very large arcs, such as in powerful search-lights, a current strength of as much as 200 amperes, is sometimes employed, requiring, therefore, an activity of about 10 K. W.

234. During the maintenance of the arc, the positive carbon, that is, the carbon from which the current enters the arc, attains at its crater, a much

higher temperature than that of the incandescent carbon. Indeed, the temperature of the negative carbon is sufficiently lower to permit the condensation of carbon vapor on its surface, so that after the arc has been maintained for some time, a nipple will be formed on the end of the negative carbon opposite the crater in the positive. The material so deposited is pure graphite. During the maintenance of the arc, the carbon vapor being exposed to the air, is consumed by oxidation. The rate of consumption of the positive carbon, however, is greater than hat of the negative, owing to the fact that it is volatilized. Roughly speaking, the rate of consumption of the positive carbon is twice that of the negative.

235. In the early history of arc lighting, the carbon electrodes employed were sawn out of blocks of the hard deposits of carbon found inside the gas retorts, employed in the manufacture of illuminating gas by the destructive distillation of coal. The enormous demand for carbon electrodes, however, soon rendered this source insufficient, and now, all carbon electrodes are manufactured. The process is essentially as follows: Pulverized carbonaceous substances, such as powdered coke or charcoal, are mixed into a stiff paste with some carbonaceous liquid, such as coal-tar, and are then moulded or forced through a die under great hydraulic pressure, dried, and submitted to a carbonizing process by baking in a furnace. During this process the cohesion of the carbon powders is increased by the carbon deposited from the decomposition of the carbonizable liquid under the influence of the heat. Since, in nearly all the arc lights in practical use, the carbons are placed vertically one above the other, it is necessary to make the carbon rods

or pencils very nearly straight, so that their axes may coincide during feeding. Where an exceedingly hard variety of carbon is required, the expedient is sometimes adopted of soaking the carbons, after carbonization, in some carbonaceous liquid, and again subjecting them to a further process of carbonization, but this is only adopted in the manufacture of carbons for special purposes.

236. The steadiness of the arc light, though dependent on a variety of circumstances, is largely influenced by the position occupied by the arc. In order to prevent a travelling of the arc around different portions of the edge of the carbon, the expedient is sometimes adopted of making the central portions of the electrodes softer, that is, more readily volatilized, than the remaining material, by the introduction of a different kind of carbon. Such carbons are called *cored carbons*. Owing to their expense, they are not extensively used in commercial lighting.

The carbon in general use, is the ordinary coreless carbon which has been electrolytically coated with a deposit of metallic copper. Although uncoated carbons are frequently employed, yet, unless special care is taken in their manufacture, they are apt to burn irregularly on the sides, and becoming pointed, are apt to interfere with the proper operation of the lamp.

237. The candle-power of an arc-lamp is very different in different directions, and, since in practice, the arc rarely remains for any length of time in a fixed position between the carbons, the candle-power as indicated by a photometer, is constantly varying. Fig. 92 represents

diagrammatically the physiologically effective luminous intensity of an ordinary arc lamp, at different angular positions about the carbons as an axis. It will be observed that at an angle of about 50° below the horizontal plane, when the carbons are vertical, the intensity is a maximum, and that it rapidly diminishes both above and below this position. The *mean spherical candle-power* is the average candle-power taken all over the surface of a sphere having the arc at its centre, and is usually about one third of the maximum candle-power, and capable of

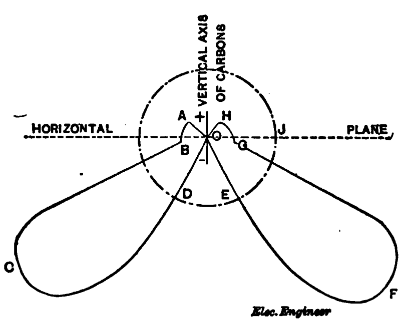

FIG. 92.

Diagram Indicating Luminous Intensity of an Arc Lamp in Different Directions.

being expressed with a fair approach to accuracy by the numerical formula

$$\text{Mean spherical candle-power} = \frac{\text{Mean horizontal candle-power}}{2} + \frac{\text{maximum candle power}}{4}.$$

The existing practice of rating the luminous power of an arc lamp by its maximum luminous intensity, is very defective, and could be preferably replaced by a statement of the mean spherical candle-power, or the total flux of light, (physiologically effective radiation).

It may be supposed that the *horizontal candle-power* of a lamp, that is, its candle-power in the horizontal plane, would be the same in all directions. This, however, is not the case, owing to the fact that the carbons burn irregularly, and that the crater, which forms the main source of light of the voltaic arc, is seldom either located exactly centrally at the end of the positive carbon, or is surrounded by walls of equal height. It becomes necessary, therefore, to take the mean horizontal candle-power of a lamp, which is usually only a small fraction of its maximum candle-power.

238. Since the carbons are consumed during use, and the steadiness of the light produced requires, among other things, that the length of the arc be maintained a constant distance apart, it is necessary that some regulating device be employed, whereby the carbons can be maintained at this distance during use. This is accomplished by means of various feeding mechanisms connected with the lamp. A great variety of feeding mechanisms have been devised depending upon the position of the carbon and upon whether both carbons are fed toward each other, or whether, as is generally the case, the negative carbon is fixed and the positive or upper carbon alone is fed.

The carbons have been placed in various positions; parallel or oblique, that is, included at all angles from zero to 180°. At one time in the history of the art, the carbons were employed parallel, as in the Jablochkoff candles, the carbons being maintained at a constant distance apart, not by the use of the feeding mechanism but by means of non-conducting substances such as kaolin placed between and consumed with them.

Nearly all commercial systems of arc-lighting at the present day, employ the carbons vertically over one another, with the positive carbon uppermost, except where the walls of buildings are to be illumined from lamps placed beneath, when the positive carbon may be placed beneath. This, of course, is on account of the fact that the crater in the positive carbon is the main source of light, the greater intensity of light being projected directly from the crater, which, when the positive is the upper carbon, will be downwards as will be seen by an inspection of the curve in Fig. 92.

239. For most commercial purposes a slight change in the height of the arc within the lamp globe is immaterial. Consequently the use of mechanism, feeding one of the carbons only is not objectionable, provided the length of the negative carbon is so adjusted that the position of the arc shall never fall outside the surrounding glass globe. For light-house purposes, and for search-lights generally, where the arc is used in connection with reflectors and the position of the arc is therefore important, the mechanism of the lamp is adapted to feed both carbons. In such cases the negative carbon is fed about one half as rapidly as the positive carbon.

240. The result of experience has been to limit the length of the carbon used for the positive electrode to about 12 inches. For long runs during winter, varying from, say, 13 to 15 hours, a single pair of carbon pencils, would be insufficient and would, therefore, necessitate recarboning during the night. In order to avoid this, the device of employing two separate pairs of carbons has been adopted, the circuit connections be-

ing such that when, by consumption, the length of one pair of carbons has been reduced a certain predetermined amount, the current is automatically transferred to the second pair. A *double-carbon*, or *all-night arc lamp* of this character is shown in Fig. 93.

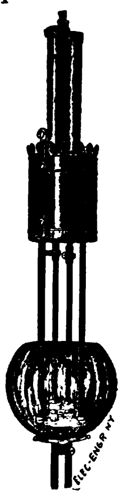

Fig. 93.
Double Carbon Arc Lamp.

SYLLABUS.

In the carbon voltaic arc, an activity of about 450 watts is usually expended, with about 10 amperes at 45 volts pressure.

The C. E. M. F. in the circuit is principally developed at the surface of the positive carbon or crater where work is being done in volatilizing carbon against its cohesive attraction.

During the maintenance of the arc, carbon is volatilized mainly from the end of the positive carbon, some of the volatilized carbon being deposited as a nipple of graphite, on the opposing surface of the negative carbon.

The mean spherical candle-power of an arc light is usually half the mean horizontal candle-power, plus one quarter of the maximum candle-power.

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Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

ARC LIGHTING.

241. In arc lamps when the current is off, the feeding mechanism permits the upper carbon to fall, until it rests on the top of the lower carbon, so that the carbons are in contact when the current is started.

On the passage of the current through the lamp, an electromagnet in the main circuit, by the attraction of its armature, separates the positive carbon the proper distance from the negative, thus establishing an arc between them, and holds the upper carbon in this position by the operation of a device called a clutch. When the consumption of the carbons increases the distance between them, the pressure rises at the terminals of the lamp, due to the extra drop in the increased resistance and length of the arc, and as soon as the pressure at the lamp terminals has risen sufficiently high, i. e., when the carbons have burnt a certain distance apart, a special magnet, wound with fine wire, so that its resistance is, say 500

ohms, placed in shunt to the lamps, attracts its armature, releases the clutch and permits the upper carbon to fall. In a well regulated lamp, the upper carbon, while in use, never actually touches the lower carbon, since the decrease in potential, caused by the decrease in the resistance of the arc, reduces the attraction of the shunt magnet, thus allowing the clamp to clutch the upper carbon swiftly.

242. In all series-connected arc lamps, some device must be employed to prevent the failure of any lamp from opening the entire circuit. This is generally

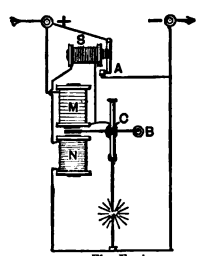

FIG. 94.
Diagram of a Form of Arc Mechanism.

accomplished by means of a special cut-out magnet, placed in the shunt circuit, and so arranged, that, whenever the pressure at the lamp terminals rises beyond a certain working maximum, this magnet shall operate and cut-out the lamp, by releasing a spring, short-circuiting the lamp terminals.

The connections of such an *automatic cut-out* are diagrammatically represented in Fig. 94, as applied to a form of feeding mechanism for a series-connected lamp. Here the lifting magnet M, wound with coarse wire and having a resistance of about 0.05 ohm, is connected di-

rectly in circuit with the arc. On the attraction of the armature, which is pivoted at B, the clutch grips the lamp rod, and thus raises the upper, or positive carbon, and establishes an arc. When, by the consumption of the carbons, the arc becomes too long, the pressure between the carbon electrodes increases and more current flows through the magnet N, of about 400 ohms resistance, wound with fine wire and placed in a shunt circuit around the electrodes. As soon as this current reaches a certain critical strength, the attraction on the armature momentarily releases the clutch and permits the upper carbon to fall, until by decrease in the length of the arc, the current through the shunt magnet decreases, when the upper magnet again overpowers it and reclutches the upper carbon.

The automatic cut-out mechanism is shown at S. It consists of an electro-magnet, wound with fine wire, and placed in shunt around the carbon electrodes. If the carbon for any reason fails to feed, the increased pressure on the terminals of the shunt circuit causes the magnet S, to be so highly energized as to attract its armature and thereby permit a spring automatically to close the short-circuit at A, and cut the lamp out.

Besides the mechanism described, a great variety of other forms have been designed for operating arc lamps. The two windings N and M, may be placed on the same core; or they may be placed on separate magnets attracting separate armatures, but in all cases a series-winding is employed for the lifting magnet, and a shunt winding for the feeding magnet.

243. The number of arc lights connected in series in a single circuit may sometimes be as great as 200, representing an aggregate pressure at the generator

terminals of roughly 10,000 volts (10 kilovolts). More usually, however, 125 lights is the limit, and in ordinary practice, from 50 to 65. For street lighting purposes, from 9 to 10 amperes is the strength of current maintained. Taking the average number of arc lights on a single circuit at, say 60, representing an aggregate pressure of 3000 volts, such a system readily adapts itself to lighting an extended area, since the size of wire employed, usually No. 6. A.W.G., has a resistance of only about 2.1 ohms per mile. Thus a circuit of, say, five miles in length would only have a resistance of 10.5 ohms in conductors, producing a drop of 105 volts, with 10 amperes of current, which would represent an activity of 1050 watts, and would be capable of supplying about 2 arc lamps.

The price asked for arc lighting service per year will, of course, depend upon a variety of circumstances, such as the size and nature of the plant, the cost of coal or water power, and the area of lighting, etc.; but taking the average case, the price would probably be from $70 to $110 per 450-watt, 50-volt arc lamp per annum.

244. Arc lamps are frequently operated on incandescent circuits, usually two in series on 110 volt circuits, or four in series across the outside conductors of three wire circuits (220 volts). In all constant-potential lamps, it is necessary to insert a resistance in the circuit of the lamp so as to ensure their proper operation. This is not necessary in series-connected lamps, since the lamps tend to automatically check one anothers variations. For this reason the pressure at the terminals of a constant-potential arc lamp will, by reason of the drop in the resistance, be two or three volts greater, than in the case of

series lamps. It would appear, therefore, that the efficiency of a series arc system would necessarily be greatei than that of the same number of lamps operated on constant-potential circuits. This, however, is not always the case, owing partly to the fact that a series generator has a somewhat lower efficiency than a constant-potential generator. Moreover, when a constant-potential incandescent circuit already exists, and but comparatively few arc lamps are required, it may be more economical to connect these directly to the incandescent circuit than to

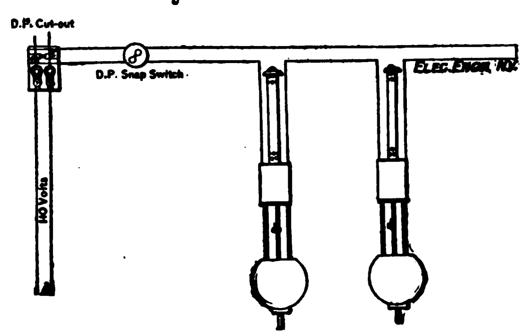

FIG. 95.
Incandescent Circuit, with Standard Lamps.

install a separate generator and circuit for their special accommodation. Fig. 95 shows the connections of a pair of arc lamps operated in series from a pair of incandescent mains at about 110 volts pressure.

245. In a station for the operation of an extensive system of arc lamps, where a number of dynamos are employed in supplying the different circuits, and where the load on such circuits may vary, a switchboard becomes necessary, whereby this load can be readily shifted from one dynamo to another. Such a swicht-board re-

quires a high insulation on account of the pressures employed and means must be adopted to prevent an arc being accidentally drawn from one bar to another. Fig. 96 represents a form of such switchboard, in which the connections are established by flexible cords connected with suitably insulated handles and protected by rubber tubes.

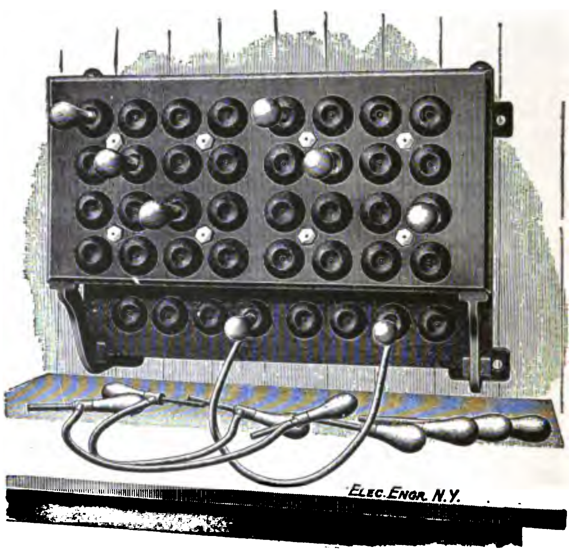

FIG. 96.
Form of Series Arc Switchboard.

246. Arc lamps are sometimes operated on alternating current circuits. In such cases, since the direction of the current rapidly changes, a definite positive crater and its opposing negative nipple are never formed. Consequently, the temperature of the two carbons is approximately the same, as also the amount of light they emit. For the same reason the distribution of

light is more regular, than in the case of the continuous current arc, and possesses two points of maximum intensity, one directed upwards and one downwards, as is shown in Fig. 97. The mean horizontal intensity also bears a greater proportion to the mean spherical intensity, or to the maximum intensity than in the case of the continuous current arc, but this proportion is more variable in alternating than in continuous current arcs.

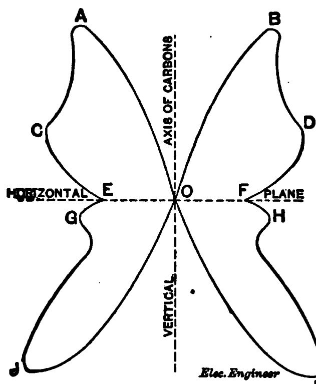

FIG. 97.
Distribution of Light from an Alternating Current Arc as measured in a particular case.

Arc lamps on alternating current circuits require from 28 to 35 volts at their terminals, according to the character, size and separation of the carbons. All alternating arcs are apt to produce a humming sound, the pitch of which depends upon the frequency of alternation. This is due to the periodic expansion and contraction of the air in the successive waves of heat produced. Alternating-current arc lamps are usually supplied by transformers, whose primaries are connected in series in the main circuit and whose secondaries are locally connected

to each arc lamp. The current employed in the primary circuit, instead of being from 9 to 10 amperes, the usual strength for continuous series-connected circuits, is commonly about 30 amperes, the secondary current strength in the lamp circuits being, however, about 9 amperes. The consumption of the carbons is nearly uniform in an alternating current arc lamp.

Syllabus.

Most arc lamp mechanisms in use, consist of an electromagnet placed in the main circuit for causing a separation of the carbons, and another electromagnet, placed in a shunt circuit, for causing their approach. In all series-connected arc lamps, an automatic cut-out device, operated by a shunt magnet, is provided for closing a short circuit past the lamp on the failure of its carbons to feed.

Arc lamps are sometimes connected in a single series circuit up to the number of 200. More commonly 125 is the limiting number, while from 50 to 65 is the number commonly employed.

Under certain circumstances it is more economical to connect arc-lamps to constant-potential mains. Such lamps require a special resistance introduced into their circuit in order to control them.

Alternating current arcs provide a more general distribution of light, than constant current arcs, owing to the fact that both carbons are at approximately the same temperature.

No. 30.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

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INTERMEDIATE GRADE.

ALTERNATING CURRENTS

247. A *continuous* E. M. F. or *current* not only continuously preserves the same direction, but, unless otherwise specified, maintains the same strength. An *alternating* E. M. F. or *current* is one which changes its direction, being alternately positive and negative. A continuous current may become *fluctuating* or *pulsatory*; i.e., it may, while preserving the same direction of current flow, vary either periodically or irregularly in its strength, but an E. M. F. or current does not become alternating unless it actually changes its direction.

The difference between an alternating and a fluctuating or pulsatory current will be seen from an inspection of Fig. 98, where a fluctuating E. M. F. or current, although represented as periodically varying in intensity, is not alternating since it is constantly directed or flows in the same direction through the conductor, being at all times represented by a line above the zero line O A; while an alternating E. M. F. or current is represented by

a line which is alternately on the positive and negative sides of the zero line, O A.

The term alternating E. M. F. or current, as employed

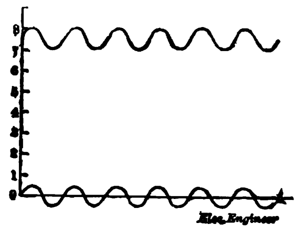

Fig. 98.
Fluctuating and Alternating E. M. F.'s or Currents.

in practice, conveys the conception not only of periodic alternation of direction, but also of periodic recurrence of magnitude. In other words, if an alternating current or E. M. F. be graphically represented by a curve, whatever may be the shape of this curve as representing direction and magnitude, this shape must be repeated in successive waves.

There may be an infinite variety of alternating E. M. F.'s and currents, not simply in regard to their magnitude, but also in regard to their manner of variation, as shown in Fig. 99.

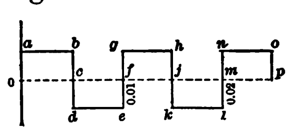

Fig. 99.
Periodic Alternating E. M. F. or Current. Rectangular Type.

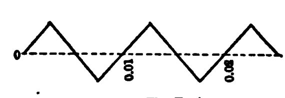

Fig. 100.
Periodic Alternating E. M. F. or Current. Zig-zag Type.

The E. M. F. may suddenly reverse its direction, as, for example, by the action of a commutator, so that the E. M. F. may suddenly change from a positive maximum

to a negative maximum, and *vice versa*, of which the graphical representation is the flat-topped type of wave; or, the E. M. F. may gradually increase and decrease at a uniform rate from the positive to the negative maxima, and *vice versa* as shown in Fig. 100, whose graphical representation is a wave of the zig-zag type. E. M. F.'s or currents of this type seldom exist in practice, but approximations to them exist, of the types shown in Fig. 101, which represents a type of alternating wave of the flat-topped variety, and in Fig. 102, which represents a type of the peaked variety of wave, such as some alternators produce.

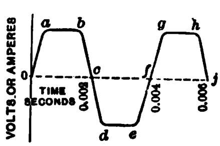

FIG. 101.

Periodic Alternating E.M.F. or Current. Flat Topped Curve.

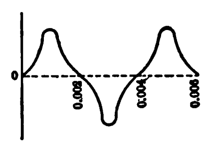

FIG. 102.

Periodic Alternating E.M.F. or Current. Peaked Curve.

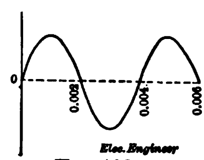

FIG. 103.

Periodic Alternating E.M.F. or Current. Sinusoidal Curve.

The E. M. F. may assume a wave form intermediate between the flat-top and the peaked varieties, and called the *sinusoidal* form, shown in Fig. 103, because its graphical representation is a sinusoid or curve of sines.

The sinusoidal form of wave may be understood from a consideration of the following preliminary principles; namely, if the disc Q R S, Fig. 104, supported on a horizontal axis A B, at O, be uniformly rotated about this axis, the vertically falling shadow *p*, of the point P, situated on the radius O P, intercepted by a horizontal sheet of paper E F G H, will execute a to-and-fro motion along the line, *p o q*, whose length will be twice the radius O P, and the

shadow will occupy different positions on this path according to the different positions of the disc. The motion of the shadow thus produced is called a *simple-harmonic or simple-periodic motion* and the E. M. F. or current, whose magnitude varies in accordance with such motion is called a *simple-harmonic or simple-periodic* E. M. F. or *current.* If now, the sheet of paper be moved steadily forwards in the horizontal plane, parallel to the axis A B, the moving shadow will trace on its surface a wave curve of the type shown in Fig. 103, and called a *sinusoid*, because the distance of any point on the curve

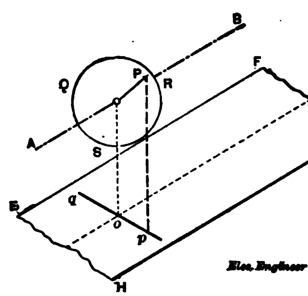

FIG. 104.
Diagram of Simple Harmonic Motion.

from the zero line *a b*, measures the *sine* of the angle at that moment included between the radius vector O P, and the vertical plane.

The shape of the sinusoid will depend upon the length of the radius vector and on the speed with which the disc rotates, as shown in Fig. 105. For example, if the radius vector have the value O J, as shown at A, the sinusoid traced for a particular speed of disc and paper is shown by the curve A B C D E F. If now, the velocities remaining the same, the radius vector be halved, as at B,

the resulting sinusoid will be flattened. On the contrary, if, as at D, the radius vector remain as before, but the velocity of rotation be doubled, the sinusoid will be sharpened.

When a conducting loop or coil is steadily rotated about any diameter in a uniform magnetic flux, a sinusoidal or simple-periodic E. M. F. will be generated in it.

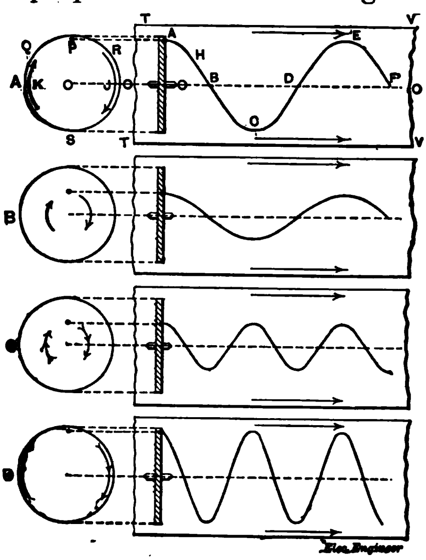

FIG. 105.

Graphical Representations of Simple Harmonic E. M. F.'s or Currents.

Commercial *alternators*, i. e., alternating current generators, do not produce true sinusoidal E. M. F.'s, but in many instances they produce so close an approximation thereto that, for the purposes of computation, their values may be regarded as sinusoidal. Even when the wave of E. M. F. gėnerated by an alternator is distinctly flat-topped or peaked, its E. M. F. is usually regarded as

sinusoidal to a first approximation, and corrections are subsequently introduced for the effects of deviation.

An *alternation*, or *semi-period*, consists of a single wave in either the positive or negative direction. A complete double alternation, that is, a double reversal, constitutes a *cycle*. Thus the wave *o a b c*, or *c d e f*, Fig. 101, represents a reversal or alternation, but the double reversal *o a b c d e f*, or *c d e f g h j*, constitutes a cycle, since the generating point returns at the end to the initial position. A cycle need not necessarily commence and terminate at the zero point; thus *b c d e f g h*, would constitute a cycle.

The time occupied by an alternating E. M. F. or current in completing a cycle is called a *period*. The period employed in commercial alternating current apparatus varies from about 0.008 to 0.04 second. In any alternating current circuit, the period of the current must always be equal to the period of the E. M. F. in the circuit.

The number of periods in a second is called the *frequency*. Thus the frequency in commercial alternating current apparatus varies between 25 ∼, that is, 25 cycles per second and 133 ∼. The frequency is sometimes expressed by the number of alternations per minute. Thus an alternator may be described as producing 16,000 alternations per minute. This corresponds to 8000 ∼ or periods per minute and, therefore, to 133.3 ∼ per second.

Assuming an alternating E. M. F. or current to be sinusoidal, its *phase* is the angle between the imaginary radius vector and the initial descending radius where the tracing point starts from the zero line in the positive direction. Thus the phase at D, Fig. 105 *A*, is zero, at E or A, is 90°, at B or F, is 180° and at C, 270°.

248. When we describe the magnitude of a continuous E. M. F. or current we simply state its constant strength, but, since the strength of an alternating current is constantly varying, some convention is necessary in order adequately to describe its magnitude. The maximum magnitude, attained during each cycle, that is, its *amplitude*, is not sufficient, owing to the very different shapes of different types of wave; nor is the mean or average value of the current, taken without regard to direction, a sufficient criterion for most practical purposes. The heating effect of electric currents or E. M. F. being their most important characteristic from a practical point of view, the strength of an alternating E. M. F. or current is conventionally defined as its effective or equivalent heating value in a continuous current circuit. Thus, if a continuous current of one ampere is capable of developing a thermal activity of a certain number of watts, in a resistance through which it passes, then any alternating current passing through the same resistance, which produces the same thermal activity, has a strength of one ampere. Since the thermal activity of a continuous E. M. F. or current varies with its square, the instantaneous thermal activity in any alternating E. M. F. or current similarly varies with its square. Thus, if the curve A B C D E F, at *A*, Fig. 105, represents an alternating current of which the amplitude O A, is one ampere, then the rate at which heat will be developed by this current in a resistance of one ohm, at the instant of time corresponding to the ordinate O A, will be $1^2 \times 1 = 1$ watt; at the point H, where the current strength is 0.5 ampere, the rate of developing heat in the resistance will be $(0.5)^2 \times 1 = 0.25$ watt. If, proceeding in this way, we were

to average the rate of expending heat in the resistance coil through one complete cycle, and take a sufficient number of measurements to obtain the necessary degree of accuracy, we should find that the mean rate of expending heat would be just 0.5 watt, or half the maximum rate, this being the law for strictly sinusoidal current waves. Since the strength of the current must be such as will develop 0.5 watt thermally in one ohm, its effective value will be $\sqrt{0.5}$ or 0.707 ampere. Consequently, the effective value of a sinusoidal E. M. F. or current is the maximum value or amplitude, divided by $\sqrt{2}$; that is, multiplied by 0.707.

SYLLABUS.

A sinusoidal E. M. F. or current is one whose graphical representation is a sinusoidal curve.

The effective value of an alternating E. M. F. or current is the value of the strength of continuous E. M. F. or current, which would produce the same thermal activity; that is, which would produce the same amount of heat in the same (considerable) amount of time.

No. 31.

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INTERMEDIATE GRADE.

ALTERNATING CURRENTS

249. From what has been said concerning the nature of simple-harmonic motion generally, it is evident that in sinusoidal current circuits we have to deal with quantities which are varying with time according to the projection, on a line, of circular motion in a plane, as represented, for example, in Fig. 106. It is, therefore, of importance, in considering such circuits to bear in mind the relation of geometrical magnitudes, as opposed to simple arithmetical magnitudes; that is to say, that not only the magnitudes of the various E. M. F.'s and currents have to be considered, but also their directions at different instants of time. For example, if two similar sinusoidal alternators be rigidly connected on the same shaft, and coupled in series, the E. M. F. of each will have the same frequency and the same magnitude. Their resultant E. M. F., when connected in series, will depend upon the exact relative position of the two armatures to each other on the common shaft; that is, upon the re-

lative phase of the E. M. F.'s and whether these are in-step or out-of-step with each other. If they are exactly *in-step*, that is, coupled in the *same phase*, so that the two waves of E. M. F. are synchronous, or rising and falling exactly together, the resultant E. M. F. of the combination will be the simple arithmetical sum, or twice the E. M. F. of either, and in-step with each, so that if each gives separately 1000 volts effective E. M. F. at a frequency of 120 $\sim$, the two so connected will give in series a total E. M. F. of 2000 volts effective, with, of course, the same frequency. If, however, the two machines are coupled in exactly *opposite phase*, so that

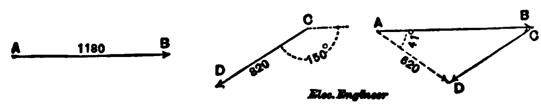

FIG. 106.

while one develops the positive crest of a wave, the other develops a negative crest, so that the difference of phase is 180°, or half a cycle between them, then their E. M. F.'s at all moments are oppositely directed, and the total E. M. F. of the combination will be zero, since in all parts of the wave, the E. M. F. of the one will exactly neutralize that of the other. At intermediate positions of coupling, or phase difference, the resultant E. M. F. will vary between 2000 volts and zero, and the phase of the resultant E. M. F. will also vary.

250. This resultant E. M. F. can be very simply determined by considering each E. M. F. as a line, or *plane vector*, revolving about one extremity, and making as many revolutions per second as there are periods per second in the frequency. Thus, let A B, Fig. 106, repre-

sent a sinusoidal E. M. F. of 1180 volts effective, and suppose that this line revolves counter-clockwise in the plane of the paper, about the centre A, 120 times in a second. At the moment when A B, is in the position shown, let a second sinusoidal E. M. F. of 820 volts effective, C D, of the same frequency, but having a phase 150°, or $\frac{5}{12}$ of a cycle in rear of A B, as shown by the direction of the line C D; then the resultant, or sum of these two sinusoidal E. M. F.'s, when connected in series, is represented in direction and magnitude by the line A D, for C D is here added geometrically to A B. The line A D, has a length of 620 volts, according to the

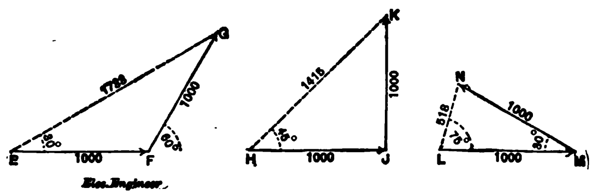

FIG. 107.

original scale, and makes an angle of approximately 41° with A B, so that the resultant E. M. F. of the combination will be 620 volts effective, lagging in phase 41° behind A B, or advancing in phase 109° beyond C D.

251. If two similar sinusoidal alternators be coupled in series, as shown in Fig. 107, so that one E. M. F., F G, leads the other, E F, by 60°, or $\frac{1}{6}$ cycle, then the sum of these two E. M. F.'s in series will be 1733 volts effective, 30° ahead of E F. Again, if they be connected in *quadrature*, that is, at quarter phase, so that J K, leads H J by 90°, their sum in series will be 1415 volts, 45°, or $\frac{1}{8}$ period, beyond H J, and behind J K; and again,

if the phase difference amounts to 150°, so that M N, makes 30° with L M, their sum in series will be L N or 518 volts effective, 75° in advance of L M.

252. The current strength in an alternating current circuit is not that which would be immediately obtained at first sight from Ohm's law. Ohm's law applies to alternating current circuits when the C. E. M. F.'s in the circuit are considered; but without taking the pains to determine what the C. E. M. F.'s become in an alternating circuit, we may consider that the impressed E. M. F.'s, that is, the E. M. F.'s produced by the source or sources, are alone operative, and that the resistance of an alternating-current circuit is different from that of the same circuit operated by continuous currents; or, in other words, that the resistance becomes converted into a hypothetical quantity called the *impedance*, and expressible in ohms. Ohm's law applied to alternating current circuits is, therefore,

$$I = \frac{E}{J} \text{ amperes, instead of } I = \frac{E}{R} \text{ amperes,}$$

where J, is the impedance.

253. There are two quantities which combine with resistance to make up the apparent resistance or impedance of alternating-current circuits, namely:

(1) Inductance, as typically developed in *choking coils* and which is always present in greater or less degree;

(2) Electrostatic capacity, as typically developed in *condensers*, and which in some circuits is almost entirely absent, but at other times exists in a marked degree.

If we suppose that a coil of insulated copper wire has a resistance of 10 ohms and an inductance, i.e., a self-

induction of 0.015 henry, and that a sinusoidal E. M. F. of 52 volts at a frequency of 100 ∼ is impressed on this coil, then, since no appreciable electrostatic capacity exists in the circuit, the impedance is composed of two parts; viz., of the resistance, and of a quantity called the *reactance*, due to the inductance of the coil. This reactance is determined by multiplying the inductance by the angular velocity of the E. M. F. The angular velocity in this case is 100 revolutions per second, and, since there are 2π radians in a revolution, 200π, or 628.3 radians, per second. Multiplying this angular velocity by the inductance in henrys, we obtain the reactance: $628.3 \times 0.015 = 9.425$ ohms. The reactance is always graphically set off at right angles to the resistance of a circuit, the inductance-reactance being set off above the line. Thus *a b*, Fig. 108, having a resistance of 10 ohms, the reactance *b c*, 9.425 ohms, is laid off above the line *a b*, and the impedance, which is always the geometrical sum of the resistance and reactance, is equal to the length of the line *a c*, joining *a* and *c*, or 13.74 ohms. If we divide this impedance into the pressure, according to the modified form of Ohm's law before stated, we have $\frac{52}{13.74} = 3.785$ amperes, the effective current strength.

254. The reactance of a condenser is equal to the reciprocal of the product of the angular velocity of the E. M. F. by its capacity in farads. Thus, if a 10 microfarad condenser be connected directly across the terminals of an alternator, supplying 1100 volts effective, at a frequency of 100 ∼, the angular velocity will be 628.3 radians per second as before, and the product of this by 10 millionths of a

farad will be (Fig. 109) $\frac{6283}{1{,}000{,}000} = 0.006283$. The reciprocal of this quantity or $\frac{1}{0.006283} = 159.2$ ohms, and the current passing into the condenser will be, by the modified form of Ohm's law, $\frac{1100}{159.2} = 6.91$ amperes effective.

255. If the condenser instead of being connected directly across the terminals of the alternator were in series with a resistance coil of 50 ohms, having an in-

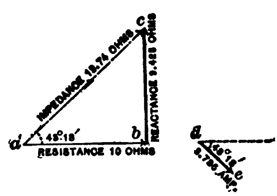

FIG. 108.

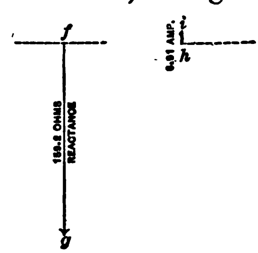

FIG. 109.

ductance of 0.02 henry, then it is necessary to determine the impedance of a circuit composed of resistance, inductance and capacity combined. The reactance in this case will be partly due to inductance and partly due to capacity. The inductance-reactance will be $0.02 \times 628.3 = 125.7$ ohms, and the capacity-reactance will be, as before, 159.2 ohms; but, while inductance-reactance is always laid off above the resistance line, capacity-reactance is always laid off below the resistance line, or in the opposite direction, because capacity and inductance tend to neutralize each other's influence. The resultant reactance in this case, as shown in Fig. 110, or 33.5 ohms, will,

therefore, be directed downwards, and the impedance of the circuit will be 50 ohms of resistance plus 33.5 ohms of reactance = 60.2 ohms of impedance, so that the current strength passing through the circuit from an alternator, maintaining 1100 volts effective at its terminals, will be $\frac{1100}{60.2} = 18.27$ amperes, which is seen to be nearly three times as much as if the condenser had been connected directly with the alternator.

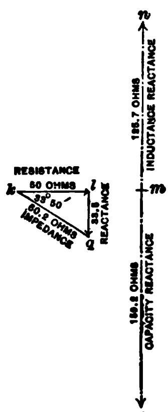

FIG. 110.

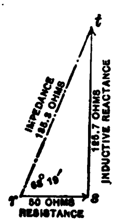

FIG. 111.

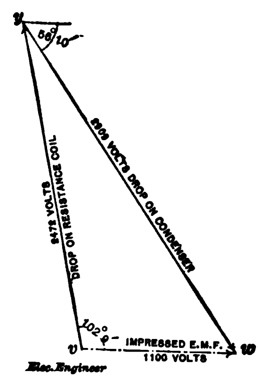

FIG. 112.

256. In a continuous-current circuit, the drop at the terminals of any resistance R ohms, traversed by a current I amperes, is $I R$, volts; so, in an alternating current circuit, the drop at the terminals of any impedance J ohms, traversed by a current of I amperes effective, is $I J$ volts. The condenser has in this case a reactance by itself of 159.2 ohms, which, in the absence of inductance or resistance, becomes the impedance J, of the condenser. The current strength I, is 18.27 am-

peres, and the drop on the condenser $I\ J$, is 18.27 $\times$ 159.2 $=$ 2909 volts. If the inductance-reactance of 125.7 ohms could be separated from its accompanying resistance in the coil, the drop on the resistance itself would be 18.27 $\times$ 50 $=$ 913.5 volts; but, since the inductance and resistance of a coil of wire cannot be separated, all that can be observed is the drop at the terminals of the two coils; namely, at the terminals of the 135.3 ohms impedance, as represented in Fig. 111, and in this case the pressure at the terminals of the resistance would be 18.27 $\times$ 135.3 $=$ 2472 volts. It follows, therefore, that a sinusoidal effective E. M. F. of 1100 volts, which never exceeds 1555 volts at the peak of the waves, can produce a pressure that could be measured with a suitable voltmeter, of 2472 volts across the terminals of the resistance coil, and a further pressure in series with this of 2909 volts across the terminals of the condenser, making a total pressure arithmetically of 5381 volts; but geometrically the sum of these two pressures can only be 1100 volts, because the impressed E. M. F., as shown in Fig. 112, is out of phase with the C. E. M. F's.

SYLLABUS.

When two sinusoidal E. M. F.'s are connected in series their resultant will be their geometrical sum.

No. 32.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ALTERNATING CURRENTS

257. In a continuous-current circuit, the reciprocal of a resistance is called a *conductance* (Sec. 33). In an alternating-current circuit, the reciprocal of an impedance is called an *admittance*. If an impedance A B, such as represented in Fig. 113, of 1.5 ohms, be transformed into an admittance, its length will be the reciprocal of the length A B, or $\frac{1}{1.5} = 0.667$ mho, and its inclination to the horizontal will be reversed, as shown at *a b*.

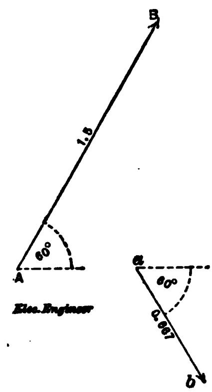

Fig. 113.
Illustrating Plane Vector Reciprocals.

In a continuous-current circuit, as has already been stated (Sec. 33), the joint conductance of a number of conductances in parallel is the sum of the separate conductances. In an alternating-current circuit, the joint admittance of a number of admittances in parallel is the geometrical sum of the separate admittances.

258. If an alternator, Fig. 114, producing a sinusoidal E. M. F. of 1100 volts effective, at a frequency of 125 $\sim$, be connected to two impedances in parallel consisting of (1) a condenser of 10 microfarads capacity and (2) a coil of 30 ohms resistance with an inductance of 0.2 henry, the angular velocity of the E. M. F. will be $6.283 \times 125 = 785.4$ radians per second, and the product of this and the capacity of 10^{-5} farad $= 7.854 \times 10^{-3}$. The impedance of the condenser is,

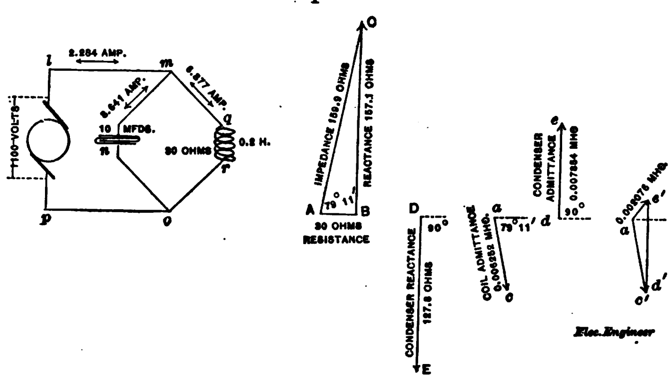

FIG. 114.
Illustrating Joint Impedance of Impedances in Parallel.

therefore, $\dfrac{1}{7.854 \times 10^{-3}}$ ohms, in a downward direction, as represented by the line D E. The impedance of the resistance coil will be the geometrical sum of the resistance A B, of 30 ohms, and a reactance B C, of $785.4 \times 0.2 = 157.1$ ohms, so that the impedance is 159.9 ohms, along the line A C.

The reciprocal of the condenser-impedance D E, will have a length $\dfrac{1}{127.3}$ or 0.007854 mho, and will be di-

rected vertically upwards instead of downwards, as shown by the line D E, set off on a suitable scale. The admittance of the coil will have a length $\frac{1}{159.9} = 0.006252$ mho, and will be set off downwards, at an angle with the horizontal, equal to the angle C A B, as shown by the line *a c*, so that the geometrical sum of the two admittances *a c*, and D E, will be *a′ e′*, having a length of 0.002076 mho. This will be the joint admittances of the two parallel admittances, and the joint impedance will be the reciprocal of this, or $\frac{1}{0.002076} = 481.6$ ohms marked off downwards. The current supplied from the alternator to this combination of impedances will, therefore, be $\frac{1100}{481.6} = 2.284$ amperes. The current which must be supplied to the condenser, considered separately, since its terminals are connected directly to the alternator, must be $\frac{1100}{127.3} = 8.641$ amperes, and the current through the coil must be, for a similar reason, $\frac{1100}{159.9} = 6.877$ amperes. It is evident, therefore, that the current through the conductors *l m* and *p o*, will be 2.284 amperes.

259. From the preceding it appears that a current of 2.284 amperes can supply a total current of 15.518 amperes. The reason is, however, that while the current in the coil is lagging considerably behind the E. M. F., the current in the condenser has a considerable lead, or is in advance of the E. M. F. The current leaving the condenser at the moment it is discharged, is,

therefore, able largely to supply the current entering the coil and only the deficit has to be made up by the current from the generator, which is nearly in-step with the impressed E. M. F.

260. In a continuous-current circuit, the activity is the product of the pressure in volts and the current strength in amperes. Thus, if a pressure of 100 volts applied to the terminals of a circuit, supplies a current of five amperes through that circuit, the activity in the circuit from the souce of E. M. F. will be 500 watts. In an alternating-current circuit, the activity is still the product of the pressure and current, provided that they are in-step, that is, co-directed. Thus, a pressure of 100 volts effective, supplied to the terminals of an incandescent lamp, taking 0.5 ampere through it, develops in the lamp an activity of 50 watts, because, there being no appreciable inductance in the lamp filament, the current through the lamp will be in-phase, or in-step, with its impressed E. M. F. When, however, the current is not in-step with the electromotive force, the activity is not the simple product of the two, but their co-directed product. Thus, if the E. M. F. acting on a coil be 10 volts, as shown by the line A B, in Fig. 115 (1), directed say horizontally, and the impedance of the coil be 2 ohms, so that the current A C, produced in the coil is five amperes, inclined at an angle of, say 60°, with the horizontal, that is, lagging 60° or $\frac{1}{6}$ period behind the E. M. F.,—then the projection of the strength of the current upon the direction of the E. M. F., that is, upon the horizontal line, will be the length A D, which in this case is just half A C, or 2.5 amperes, and this multiplied by the pressure will give the activity, or 25 watts. It is evident, there-

fore, that the further the current lags behind, or advances before, the E. M. F., or, in other words, the greater the difference of phase between the current and E. M. F., the less will be the activity, or rate of expending energy, in the circuit for a given current strength. The lag or lead of the current in a circuit cannot exceed 90° from the E. M. F. producing it. It can never in practice actually equal 90°, for in such a case, as represented in Fig. 115 (2), the projection of the current on the line of E. M. F. would vanish, and the activity in the circuit would be sustained without any energy being supplied, which, of course, is an impossibility.

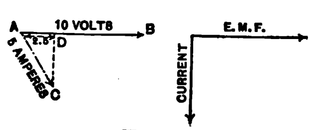

FIG. 115.

Illustrating the relations between E.M.F., current, and activity, in sinusoidal current circuits.

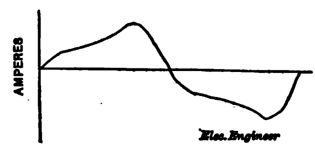

FIG. 116.

Type of current wave supplied to a ferric circuit transformer on light load.

261. In calculating the power in any alternating-current circuit, the true activity, divided by the apparent activity, is called the *power factor*, and in the case of sinusoidal currents is the ratio of the projection of the current on the line of E. M. F., to the current strength. Thus in Fig. 115 (1), the projection of the current being half the current strength, the power factor in that circuit is 0.5; or, the true activity being 25 watts, and the apparent activity $10 \times 5 = 50$ watts, the power factor $= \frac{25}{50} = 0.5$. When the currents, or E. M. F.'s, are not sinusoidal, the projection of the current strength upon the line of E. M. F. cannot be resorted to,

but in every case the ratio of the true to the apparent activity is the power factor.

For example, the waves of current supplied to a ferric-circuit transformer (a transformer whose magnetic circuit is completely made up of iron) are far from being sinusoidal, when the transformer is idle, or on light loads. The type of such a wave is shown in Fig. 116, where the maximum amplitude or crest of the wave, instead of occuring midway between the zero passages, as in a sinusoidal wave, is displaced along the surface, owing to the influence of hysteresis in the iron, because a large change of current is necessary to produce a small change in flux at the turning point in the magnetic cycle (Sec. 154, Fig. 65). It is difficult to assign an angle of lag to such a wave; and, consequently, the ratio of the projection to the actual current strength cannot be determined, while the apparent and actual activities in a circuit can always be found by means of a suitable voltmeter, ammeter and wattmeter. In transformers, however, the current tends to become more nearly sinusoidal as their load, that is, their output, is increased, so that the waves of current supplied by a sinusoidal alternator to a circuit supplying transformers at different loads are seldom so distorted as those shown in Fig. 116.

262. The power factor of an alternating current transformer with ferric circuit varies from 0.7 at no load, to, perhaps, 0.99 in large transformers at full load, but in aero-ferric transformers, whose magnetic circuits are formed only partly of iron, the power factor at no load may be as low as 0.4. The power factor of an alternating-current, synchronous motor, may vary from 0.9 to 1.0, and in an alternating current induction mo-

tor, from 0.5, on light load, to 0.85 or 0.9 at full load. The average alternating-current circuit has a power factor of about 0.95, so that the apparent activity is only about 5 per cent. in excess of the actual activity.

263. The ratio of the impedance of a circuit or conductor to its resistance is called its *impedance factor*. The impedance of a line or conductor is almost always greater than its resistance, owing to the inductance of the conducting loop, and the impedance factor shows how many times greater than the resistance this impedance is. The impedance factor depends upon the frequency of alternation and increases with the size of conductor. Thus at 120 ~, the impedance factor of two No. 4 A. W. G., copper wires, suspended in air parallel to each other, at an interaxial distance of five feet, is 1.6, so that the apparent resistance of such a pair of conductors would be 60 per cent. in excess of their ohmic resistance. The ratio of the reactance of a conductor or circuit, to its ohmic resistance is called its *reactance factor*, and measures the tangent of the angle of lag or lead in the case of sinusoidal currents.

264. It has already been stated (Sec. 45) that the apparent resistance of a rod or cylinder is greater for alternating than for continuous currents. The reason for this is to be found in the fact that if we consider, for example, a long straight conductor, carrying 10 amperes, the magnetic flux will encircle the axis of this wire in an alternately right-handed and left-handed direction at each alternation of the current. Of this flux, perhaps 80 per cent. will lie outside the wire, and the remainder, or 20 per cent., will be contained in the substance of the wire, there being no magnetic flux at the axis or centre. The

pulsating magnetic flux induces a C. E. M. F. directed along the wire and opposing the establishment of the current in it. While, however, the central portions of the wire have the full C. E. M. F. produced by all of this flux, the external or superficial portions have a C. E. M. F. only 80 per cent. as great, since it is produced by the external flux only. The result will be that the impedance of any filament of wire near the centre will be greater than that of a corresponding filament near the outside, and the current will, therefore, be distributed more densely in the outer layers.

265. The imperfect penetration of an alternating current into the interior portions of a conducting wire is called the *skin effect* of alternating currents. At high frequencies, and in large sizes of wire, the skin effect may be very considerable, but for commercial frequencies and with the sizes of wire employed in overhead construction, the impedance due to skin effect is very small. Thus in the case of a No. 000 copper wire, carrying currents whose frequency is 140 ~, the impedance, owing to the influence of imperfect current penetration is only 1.6 per cent. greater than the ohmic resistance. In iron wires, however, this influence is much more marked, owing to the greater proportion of magnetic flux existing within the substance of the alternately magnetized wire. The impedance of a No. 7 A. W. G. iron wire at 140 ~ may be double that of its ohmic resistance, owing to the effect of imperfect current penetration.

In telephony the advantage of copper wires over iron wires is principally ascribed to their reduced skin effect.

No. 33.

Electrical Engineering Leaflets,

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INTERMEDIATE GRADE.

ALTERNATORS.

266. The number of poles on a continuous-current generator is largely a matter of economy and convenience in construction. In an alternator, the number of poles is prescribed, as soon as the frequency and the number of revolutions of the armature per second has been determined upon, since these two considerations determine the frequency of alternation. A bipolar alternator, generates one cycle for each complete revolution of its armature; a four-pole machine, generates two cycles for each complete revolution of its armature; and a machine of p, poles will, therefore, generate $\frac{p}{2}$ cycles for each revolution of its armature. Consequently, the frequency of an alternator is $\frac{n\ p}{2}$, cycles per second, where n, is the number of revolutions of its armature per second; thus an alternator of 16 poles, making 16 revolutions per second, would have a frequency of 128 ∼. Some *inductor*

alternators, however, which revolve masses of soft iron instead of wire, produce twice as great a frequency, or a frequency of $n\ p$, cycles per second.

267. The character of the E. M. F. wave generated by an alternator, depends upon the dimensions of the pole pieces and winding spaces, so that by varying the distance between the poles, or their shape, or the distance between the coils on the armature, as well as the shape of the space these occupy, the type of E. M. F. wave may be varied.

268. In most alternators, the armature is revolved in a fixed field frame. From this the E. M. F. generated is connected with the circuit they supply through brushes resting on *collector rings*, in lieu of the commutators employed in continuous-current generators. In other alternators, however, the armature is maintained at rest, and the field frame revolved about it. In such machines the current is supplied through brushes and collector rings to the magnets, while the armature is connected directly to the line. In still other forms of alternators, the field and armature are both fixed, and masses of iron are used to vary, by their revolution, the magnetic circuits between the two. Such alternators are called *inductor alternators*.

269. The coils in alternating armatures are either of the Gramme ring, the drum, the disc, or the pole armature type. The most usual, owing to its convenience of construction, is the pole type, but other forms are in common use, especially in Europe. The armature coils are sometimes connected in series and sometimes in parallel-series, as shown in Figs. 117 and 118. When wound

in parallel-series, twice the number of armature turns is required for the same E. M. F.

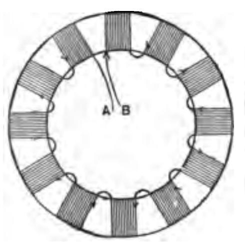

FIG. 117.

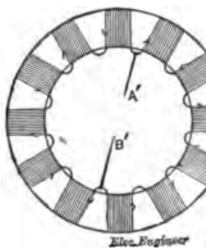

FIG. 118.

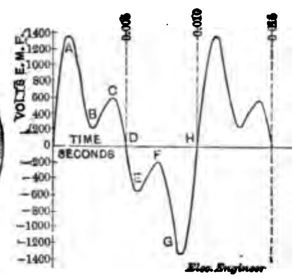

FIG. 119.

270. When a wave of E. M. F. or current is not a simple sinusoid, for example, in the case of such a wave as is represented in Fig. 119, it is sometimes convenient to

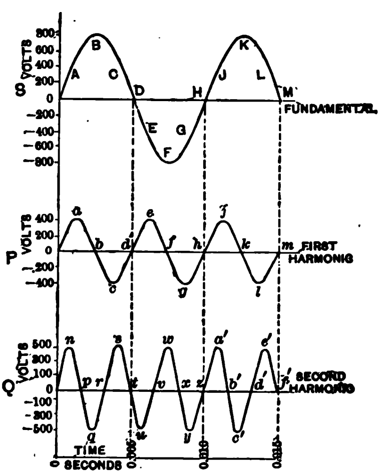

FIG. 120.

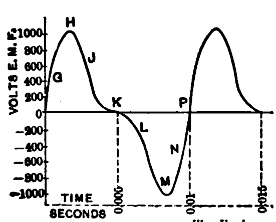

FIG. 121.

regard the wave as capable of being analyzed or decomposed into components, all of which are sinusoids; that is, into a fundamental sinusoid and its harmonics. It can be shown that any periodic wave possessing a definite frequency, no matter how complex its form, can be resolved into a fundamental sinusoidal wave of the same frequency, and a number of ripple chains, or harmonics, each harmonic having a frequency some integral multiple of the fundamental frequency. Thus Fig. 120, represents at S, a sinusoidal wave of E. M. F. having a frequency of 100 $\sim$, and an amplitude of 800 volts. Its first harmonic,—that is, a sinusoidal wave of double the frequency, and which in this case has an amplitude of 400 volts, and starts in phase with the fundamental,—is represented at P. Its second harmonic, having three times the frequency of the fundamental and in this case with the amplitude of 500 volts, also starting in phase with the fundamental is seen at Q. If two alternators, respectively producing the waves S, and P, were rigidly coupled on the same shaft, the E. M. F. they would jointly produce in the circuit, would be represented in Fig. 121 where the wave O G H J K, is the sum of the component waves *o a b c d*, and O A B C D, Fig. 120. The resultant wave is observed to be *asymmetrical;* that is to say, if the positive wave O G H J K, Fig. 121, be revolved about the line O K, so as to be completely reversed in direction, it will not coincide with the following negative wave K L M N P. This lack of symmetry is owing to the addition of the odd harmonic; for, the first, third, fifth, etc., harmonics have the property that when added to the fundamental wave, either singly or in combination, they produce asymmetry about the zero line, and since

all properly constructed alternators produce symmetrical waves of E. M. F. and current, in which each wave differs from its successor or antecedent in direction only, such harmonics do not exist in the forms of wave commercially employed.

Similarly if in Fig. 120, the three waves P, Q, and S be combined, their resultant will be the wave shown in Fig. 119, whose amplitude is about 1330 volts. This wave is also asymmetrical, owing to the presence of the first harmonic.

271. Fig. 121 shows the effect of combining a fundamental wave F, of a particular amplitude and phase, with its second harmonic. F + A, the resultant of F and A, is of the flat-topped type, while F + B, similarly compounded of F, and B, is of the peaked type. A and B, have the same amplitude, but differ in phase by half a period, or 180°. Both the resultant waves are symmetrical, and it can be demonstrated that the addition to a fundamental wave of any number of even harmonics, of any amplitude or phase, will always produce a symmetrical wave, no matter how complex its form. The flat-topped or peaked type of alternating E. M. F. or current may, therefore, be equivalent to the result produced by the presence of a prominent second harmonic.

272. When a complex-harmonic E. M. F. is impressed upon a circuit, the current may be considered as the sum of all the component currents which each component of E. M. F., considered as a separate alternator, could independently produce in the circuit. The upper harmonics have so high a frequency that the reactance offered to them by inductance in the circuit produces a

high impedance to their current, and, consequently, in a circuit containing considerable inductance, the upper harmonics in the current are greatly weakened, so that the wave of current tends to approach the fundamental sinusoid. In fact, it is seldom necessary to introduce more than a second and fourth harmonic into the harmonic analysis of any practical alternating-current wave. On the other hand, the effect of hysteresis in iron cores linked with a conducting circuit, is, as we have already seen, likely to produce considerable distorsion of current wave type.

273. When an alternating E. M. F. or current is spoken of as possessing harmonics, it is not, therefore, to be inferred that those harmonics are actually present, but that the type of curve is such as could be produced by the admixture of certain harmonics, with a fundamental having the frequency of the wave, and that the effects of such an E. M. F. or current, would be duplicated in the E. M. F. or current under consideration. In fact, with the alternating E. M. F.'s and currents in commercial use, the consideration of harmonics may for many purposes be neglected.

274. Two methods of winding alternators are in common use, viz., the series and the parallel-series, as already shown in Figs. 117 and 118. In the former, the total E. M. F. of all the coils is utilized, but the full pressure of the alternator is developed between the two neighboring extremities A, and B. In the latter, twice as many turns have to be wound on the machine to produce the same E. M. F. as in the former case, but the points of maximum pressure are now as far removed on the armature as possible.

Alternators may be *self-excited* by commuting a current from a small special winding, and directing this rectified current through the field magnets. In almost all cases, however, alternators are *separately excited* by means of a small, continuous-current generator, operated on the same shaft or by a belt running from an armature shaft.

Alternators are frequently *compound-wound.* This winding may be arranged in one or two ways; viz., either the main current supplied from the armature is led through a shunted commutator, on the armature shaft, which is connected with a special winding on the field

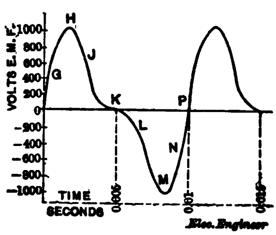

FIG. 122.

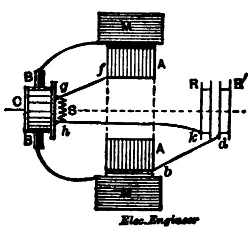

FIG. 123.

magnets, so that a portion of the outgoing current is commuted and sent through the field winding, as shown in Fig. 122; or a transformer is placed in the path of the outgoing current, and the secondary coil is connected through the commutator with the field winding, so that as the outgoing current increases in strength the field winding receives additional excitation.

275. In continuous current generators the drop in the armature is almost entirely owing to the resistance of the armature; some little being, however, due to a C. E. M. F. of self-induction in the coils undergoing com-

mutation, and some to armature reaction and C. M. M. F. In an alternator, however, the drop is not only due to the resistance, but also to the reactance of the armature, so that the drop is increased from IR, to IJ, volts; J, being the impedance of the armature. In addition to this, there is usually some drop due to armature reaction and C. M. M. F., but as there is no commutator, there is no loss due to commutative action.

Syllabus.

The frequency which an alternator has to supply determines the number of its poles when its speed of rotation is given.

The character of the E. M. F. wave of an alternator depends upon the relative size and spacing of the poles and armature winding.

Most alternators revolve their armatures; some revolve their fields, and a few revolve a mass of iron, forming a portion of their magnetic circuit.

Alternating waves of E. M. F. and current, when not strictly sinusoidal, may be resolved into a fundamental and a member of harmonics.

The combination of a fundamental with any of its odd harmonics produces an asymmetrical wave with respect to the zero line, but its combination with any of its even harmonics produces a symmetrical wave.

No. 34.

Electrical Engineering Leaflets,

—BY—

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INTERMEDIATE GRADE.

ALTERNATORS.

276. Alternators employed for incandescent lighting usually have a frequency of from 125 ~ to 133 ~, and should have a frequency above 35 ~ in order to ensure steadiness of the light. Below 30 ~ incandescent lamps appreciably flicker, showing pulsations in the light emitted corresponding to the pulsations of the current, especially with high pressure, high efficiency filaments, which have necessarily a very small cross section and a high temperature.

A type of alternator suitable for incandescent lighting at a frequency of 133 ~, is shown in Fig. 124. This machine has a commutator provided at M, for rectifying the induced current through the compound-wound field magnets, so as to maintain a constant E. M. F. at collector rings R, R′, under all conditions of load. It has 28 poles and makes 571 revolutions per minute with a capacity of 450 K W.

The E. M. F.'s supplied by such alternators are 1000,

2000 or 3000 volts effective, representing a maximum E. M. F. in each cycle of about 1414, 2828, or 4242 volts, on the assumption that the waves of E. M. F. are sinusoidal. The effective pressures at machine terminals may be five to fifteen per cent. in excess of the E. M. F.'s to be supplied in the mains in order to allow for drop in conductors.

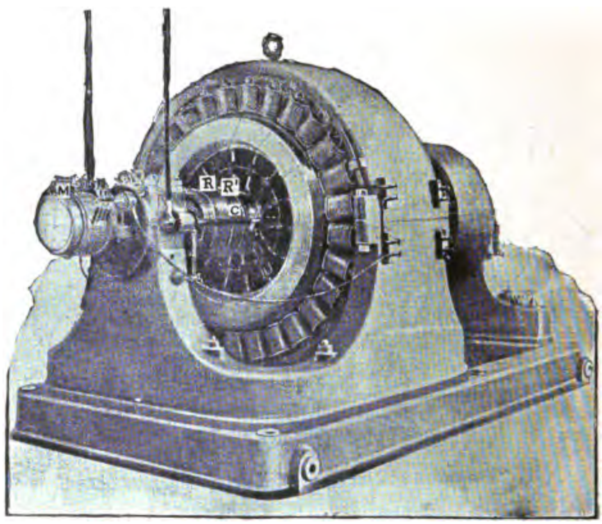

FIG. 124.
Alternator for Incandescent Lighting.

277. In all incandescent alternators, the inductance and, therefore, the reactance of the armature is kept as low as conveniently possible, so as not to obtain an unduly large impedance in the armature of the machine, and so as to prevent an excessive drop in the armature under load. In alternating arc generators, however, the armatures are required to vary automati-

cally the E. M. F. at the collector rings in conformity with the number of lamps that are operated in series in the circuit through the medium of their respective transformers. This is accomplished by giving to the armature a large inductance and consequent reactance, and also by arranging for a powerful reactive effect between the C. M. M. F. in the armature and the M. M. F. of the field. By this means the drop of pressure in the armature, and the reactive M. M. F., keep the pressure at collector rings down to that required for supplying under all conditions of load, a practically uniform current through the line.

278. Alternators supplying incandescent or arc lamps, furnish a single alternating current through one pair of mains from the collector rings. Such a current is capable of driving a similar alternator as a motor, but only when the motor is in step with the alternator. Such motors can either not be started at all, or can only be started from rest under light load, but once in step with the generator will run under full load from its current. These motors are called *synchronous* motors. In order to employ an alternating current motor, capable of being started with full torque from rest, which is the requirement of most machinery, *multiphase* currents have at present to be employed; that is, two or more currents, differing in phase by different amounts, require to be simultaneously sent through the motor in different circuits. At present there are only three varieties of multiphase currents in commercial use; namely, *diphase*, *triphase* and *monocyclic*.

279. Two alternating E. M. F.'s are called diphase E. M. F.'s, when they have the same frequency, magnitude and wave character, but differ in phase by a quarter

cycle, or 90°, being, therefore, *in quadrature.* Such E.M.F.'s are as shown in Fig. 125, where O A, indicates an E. M. F. of 1100 volts rotated at a definite angular velocity about the point O, but always in quadrature with an equal E. M. F. O B, which rotates around O, with it, so that when O A, has its full length the projection of O B, on a horizontal line vanishes. When O A, reaches the position shown in Fig. 126; namely, after $\frac{1}{8}$ of a period has elapsed, the projection of O A′, on the horizontal line will be *o a′*, or 778 volts, and the projection of O B, still at right angles to O A, will be *o b*, or 778 volts negative. It is evident, therefore, that when one E. M. F. has its maximum, the other E. M. F. has its zero.

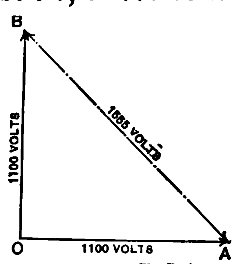

FIG. 125.
Diagram of Diphase E. M. F.'s.

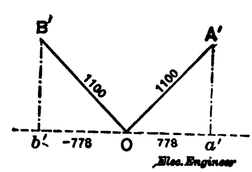

FIG. 126.
Diphase E. M. F. Diagram.

The current, which these two E. M. F.'s will send through independent circuits, will also be in quadrature, if the impedances of those circuits are equal; for, the lag of each current behind its own E. M. F. will be the same in each circuit. In some cases, four wires and two separate circuits are employed for the distribution of diphase currents as shown in Fig. 127, while in other cases three wires are employed, one wire forming a common return, as in Fig. 128. Each circuit,

considered separately, is an ordinary uniphase circuit in which incandescent lamps, arc lamps or synchronous motors can be operated, but the combination of the two currents enables non-synchronous or inductive motors to

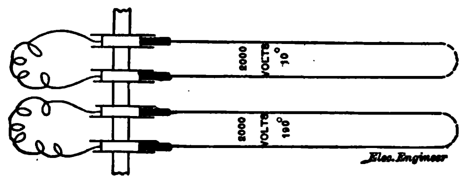

FIG. 127.
Diphase Connections, Separate Circuits.

be operated. In Fig. 128, the E. M. F. between neighboring wires is seen to be 2000 volts effective, while between outside wires, the E. M. F. is 2828 volts effective, and this will be true whether the E. M. F.'s are sinusoidal or not; for, as shown in Fig. 125, the E. M. F., A B, is 1.414 times greater than either O A, or O B, by geometry.

Diphase E. M. F.'s are generated by two sets of coils so wound on the armature, with respect to the field poles, that the E. M. F. generated in one is 90°, or $\frac{1}{4}$ cycle, ahead of the E. M. F. generated in the other.

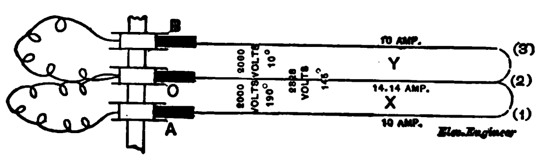

FIG. 128.
Diphase Connections, Interconnected Circuits.

280. Three alternating E. M. F.'s are called triphase E. M. F.'s, when they have the same frequency, magnitude and wave character, but differ in phase $\frac{1}{3}$ cycle or 120°. Such a system of E. M. F.'s is represented in

Fig. 129 where O A, O B, and O C, are three triphase E. M. F.'s, each of 1000 volts effective, revolving together about the point O, with a definite angular velocity.

281. Triphase E. M. F.'s are generated by three sets of coils so wound on the armature with respect to the field poles, that the E. M. F.'s in them are 120° apart. There are two methods of connecting the windings externally; namely, the *star-method*, indicated in Fig. 130, where the three windings are brought to a common connection O, and the *triangular method* represented in Fig. 131, where the three windings are connected in one loop

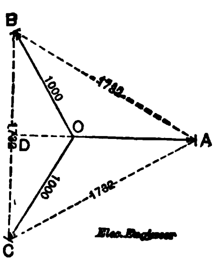

FIG. 129.
Triphase E. M. F. Diagram.

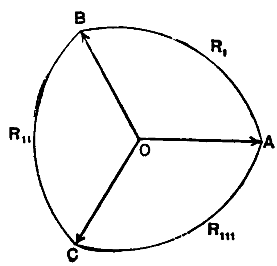

FIG. 130.
Star Triphase Winding.

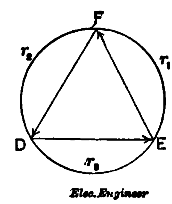

FIG. 131.
Triangle Triphase Winding.

or series D E F. Whichever method is adopted the E. M. F. is always measured between any two of the three terminals A B C, or D E F. In the star winding, the E. M. F. between any two terminals as A and C, Fig. 129, is 1732 volts effective or 1.732 times the E. M. F. in the winding O A, O B, or O C, as is evident from the geometry of the figure, so that if the E. M. F. between three terminals is 1732 volts, that between any terminal and the common connection is 1000 volts. On the contrary, when connected in the triangular system, the E. M. F. between terminals is the E. M. F. of the winding. The out-

put, however, of a machine will, under both conditions, be the same, and in fact will be the same whether the machine be divided in three parts connected in triphase, or into a single winding and worked uniphase.

282. A recent combination of the uniphase and multiphase systems is called the *monocyclic* system. This system is intended to be a uniphase system in so far as regards electric lighting over an extended area by two wires, but when multiphase motors are to be driven, a third and smaller wire called the *power wire* is employed carrying a special pressure to such multiphase motors.

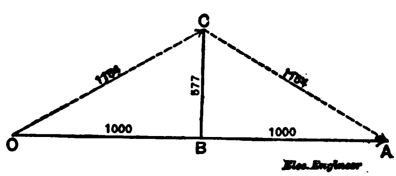

FIG. 132.
Monocyclic E. M. F. Diagram.

The arrangement of E. M. F.'s in a monocyclic generator is represented in Fig. 132, where O A, is the principal E. M. F. of the generator and is here represented as of 2000 volts effective E. M. F., revolving at definite angular velocity about the extremity O. This E. M. F., connected to two collector rings, furnishes a uniphase current for incandescent and arc lighting, and also for synchronous motors. A separate winding of smaller cross-sectional area and fewer turns, produces the E. M. F., B C, of 577 volts effective, which is connected between a third collector ring and the middle of the principal winding O A. This E. M. F. is arranged to be generated in quadrature with O A, as shown in the figure. Between terminals O, and

A, there will thus be an E. M. F. of 2000 volts, between O, and C, 1154 volts, leading O A, by 30° and between C, and A, 1154 volts, lagging 30° behind O A, consequently O C and C A, are separated in phase by 60°. The power wire from C, being carried to the premises where an induction motor is to be operated, two transformers are installed each for half the power required. One transformer is connected to the wires O and C, as shown in Fig. 133, and the other to the terminals A and C. The E. M. F. induced in the secondary winding of these trans-

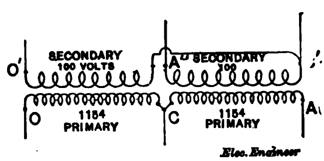

FIG. 133.
Monocyclic Triphase Transformer Connections.

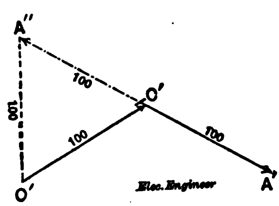

FIG. 134.
Combination of Secondary Monocyclic E. M. F. into Triphase System.

formers may each be, say, 100 volts effective, but a relative angular position of O C and C A, in Fig. 132, or O' C' and C' A', in Fig. 134. By reversing the connection of the second E. M. F., C' A', we obtain an E. M. F. C' A'', Fig. 134, so that the three terminals of the two transformers O', C' and A'', have between them three triphase E. M. F.'s, each equal to 100 volts, as shown in Fig. 134, and to these terminals the triphase motor wires are attached.

No. 35.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

INTERMEDIATE GRADE.

ALTERNATING CURRENT TRANSFORMERS

283. An alternating-current transformer consists essentially of an induction coil in which an alternating E. M. F. is induced in a secondary circuit by the variations of an alternating current in the primary circuit.

Suppose that a laminated ring of iron wire c c c, Fig. 135, be wrapped with a primary coil P, and an alternating E. M. F. of 1000 volts be impressed on its terminals. If the coil has 500 turns and a resistance of R, ohms, then a certain effective current strength I, will pass through the coil. Since the current is alternating, the M. M. F. it produces sets up an alternaing flux through the coils and establishes in it a C. E. M. F. The geometrical sum of this C. E. M. F. and the drop, will be 1000 volts; thus, if the resistance R, be two ohms, and the current strength I, one ampere, the impedance of the coil will be 1000 ohms, and the geometrical sum of the C. E. M. F. and the drop of 2 volts, will be equal to the E. M. F. of

1000 volts at the terminals. The C. E. M. F. must therefore be very nearly 1000 volts.

284. If now a secondary coil s, be wound on the ring as shown, the flux from the primary coil may, neglecting leakage, be considered as passing entirely through the secondary coil. If the number of turns in the secondary coil be 50, the E. M. F. induced in it will be very nearly $\frac{50}{500}$ths of that at the primary terminals, 100 volts. If the secondary circuit be opened, the presence of the secondary coil has no effect upon the primary circuit, but if the secondary coil be closed through a resistance, a current will flow through the secondary circuit, and will produce a M. M. F. in the magnetic circuit, counter to the M. M. F. of the primary current. The primary M. M. F. is, therefore, weakened, and the C. E. M. F. in the primary coil weakened, and the impedance in the primary coil being reduced, an increased current strength flows through it from the primary mains. This increase in current is sufficient, under the new conditions, to re-establish the flux and C. E. M. F. required in the primary circuit. As the load in the secondary circuit is increased, the impedance of the primary circuit diminishes, and, not only does the primary current increase, but it comes more nearly into phase with the primary impressed E. M. F., that is, both the current strength and the power factor increase. In other words, an alternating-current transformer is self-regulating, under all variations of load, up to the limit of the apparatus.

285. In the alternating-current transformer shown in Fig. 135, the primary and secondary coils are wound on the outside of the iron wire ring forming the

magnetic circuit. This arrangement is objectionable in practice on account of leakage, as illustrated in Fig. 136. Preferable forms are shown in Fig. 137, where the primary and secondary coils are brought nearer together and where they are more closely surrounded by iron, thus reducing the leakage. The flux paths are roughly indicated by the arrows. Other forms, in which the iron lies outside the coils, are shown in Figs. 138 and 139, where the primary and secondary terminals are represented by the letters P P, and S S, respectively. Here the primary and secondary coils are surrounded by U-shaped stampings of sheet metal, alternately placed

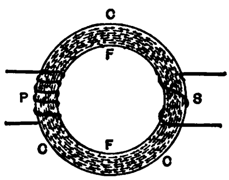

FIG. 135.

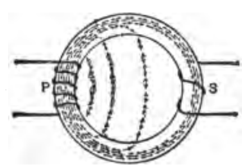

FIG. 136.

above and below so as to produce a thick and short magnetic circuit. The leakage in such a transformer is comparatively small, but the transformer has to be entirely dismantled, in order to replace an injured coil. Still another form is represented in Fig. 140, where two coils C C and *c c*, are clamped together by a laminated iron frame I I, with a laminated core passing through the centre of the coils.

286. The output of a transformer is limited either by the amount of drop in the secondary coil, or by the elevation of temperature of the apparatus under full load. A transformer of, say from 1 KW. to 50 KW. capa-

city, should not have more than 4 per cent. drop at secondary terminals when the primary pressure is maintained constant. If the apparatus is heavily overloaded, and especially if the design is inferior, the drop at the secondary terminals will become more than can be permitted for the purposes of incandescent lighting.

The heating of a transformer arises from expenditure of energy in the primary and secondary circuits, of the type $I^2 R$, and in eddy currents in the conductor and core, and from hysteresis in the iron core. The elevation of temperature of the transformer, at full load, should

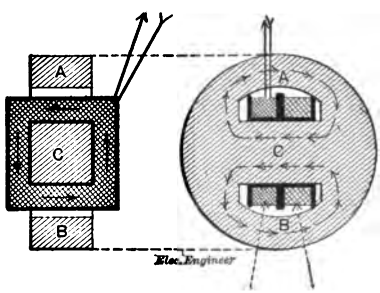

FIG. 137.

FIG. 138.

not be over 50° C. Good transformers are designed so that the temperature elevation shall not exceed 40° C. Since, in large transformers the surface which permits the escape of heat is relatively much smaller than in small transformers, artificial means are required to prevent undue heating.

287. If there were no losses of energy in a transformer, it is evident that the activity delivered in the secondary circuit would be equal to the activity absorbed at the primary terminals, and that the exciting

or magnetizing primary current at no load would be in quadrature with the impressed E. M. F. In all transformers the principal loss is due to hysteresis, which is practically the same at all loads, while the losses due to $I^2 R$, in the conductors, are, of course, dependent upon the output. If, therefore, we measure the expenditure of activity in the primary circuit of a transformer, when

FIG. 139.

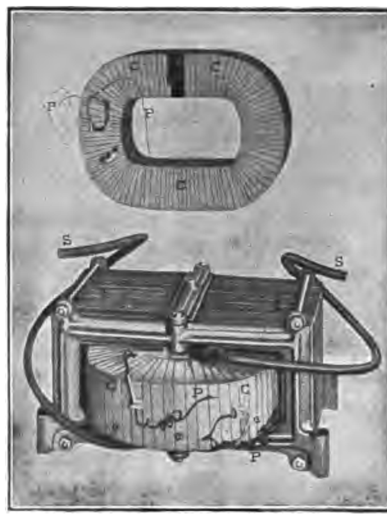

FIG. 140.

its secondary circuit is open, and we know the resistance of the primary and secondary coils, we can readily estimate the amount of loss which will take place at any given load. The losses by eddy currents are practically constant at all loads, and, by a proper lamination of the iron core, may be rendered practically negligible. It is usual to employ charcoal iron or soft steel for transformer plates, having a thickness of about 0.015″.

288. The efficiency of alternating current transformers increases with their size and varies with their load. Large transformers, of say 50 KW. capacity, have an efficiency of more than 0.98 at full load, and about 0.95 at quarter load, while a small transformer, of say 0.5 KW. capacity, for about 10 incandescent lights, may have a full load efficiency of 0.9, and 0.7 at quarter load. Practically, however, the most important factor in the efficiency of a transformer is its *all day* or *average efficiency;* that is, the ratio of the total output to the total in-take during the 24 hours. Most transformers employed in incandescent lighting have to be operated at no load for, perhaps, 18 hours in the 24. Here, the loss in hysteresis is an important consideration. It is evident that it may often be more economical to supply incandescent lighting from a few large transformers, with low pressure mains, instead of from a number of small transformers, each connected to its own consumption circuit, since the all-day efficiency of a large transformer may be 0.96, while that of a number of small transformers may average only 0.75.

289. The power factor of a transformer depends upon its size, its load, and on the character of its load. For an unloaded transformer the power factor is usually about 0.7, so that the activity absorbed is only about 70 per cent. of the product of the volts and amperes at primary terminals. At a full load of incandescent lamps, i. e., with an non-inductive load, the power factor may be 0.99. When, however, the load on the transformer is inductive, as, for example, when motors are operated in the secondary circuit, the power factor will not only be comparatively small in the secondary cir-

cuit, but will also be appreciably reduced in the primary circuit. Thus, the power factor in the primary circuit of a large transformer might be 0.99 at full non-inductive load, but would, perhaps, be only 0.9 at full inductive load. The effect of an inductive load is not only to diminish the power factor, but also to increase the drop at secondary terminals.

290. The frequency of alternation at which transformers are operated has an important influence upon their size and efficiency. Since the E. M. F. induced depends on the rate of change of the flux, the greater the frequency the greater will be the E. M. F. induced for a given flux, and, consequently, the smaller will be the flux required for a given C. E. M. F. The size and weight of a transformer can, therefore, be reduced within certain limits by increasing the frequency, just as the size and weight of a generator or motor can be reduced by increasing its speed of revolution for a given output.

291. The pressures commercially employed in alternating-current primary circuits are usually 1000 or 2000 volts, and in some cases as high as 10,000 volts, while in the secondary circuit the E. M. F. is usually 50 or 100 volts, the secondary coils being usually in two halves, each for 50 volts, and capable of being connected either in parallel or in series.

Since any failure in the insulation existing between primary and secondary circuits in a transformer brings the primary pressure into the consumption circuit, and, therefore, renders the secondary circuit dangerous to handle, the insulation between the coils themselves and

between the coils and iron frame has to be carefully provided for in manufacture.

On account of the high-pressure connections, transformers are generally placed outside the building they are intended to supply and secondary wires carried from such point into the building.

INDEX.

ERRATA.

Page 120, Syllabus. For 5.771×10^{-7} read $5.771\, \mathcal{B}^2 \times 10^{-7}$.